

With the Author's compliments.

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THE BALUCHISTAN EARTHQUAKE OF THE 21ST
OCTOBER 1909.

BY

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(With Plates 4 and 5.)

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I. INTRODUCTION.

AS might be expected in a region of folded mountains of comparatively recent or still continuing uplift, Baluchistan is from time to time visited by earthquakes of greater or less severity. Of those recorded the most important in its topographic effects was that of Sanzal on the 20th December 1892,¹ though exceeded in its destruction of life by the subject of the present account.

The Kachhi plain, the locality of this earthquake, is a bay of alluvium (*pat*) enclosed on three sides by the great flexure of the ranges between the Bugti and Kirthar hills. The railway line between Jacobabad and Sibi traverses this from south to north, crossed at an angle of about 40° by the elongated oval of the epicentral tract.

Unfortunately only two earthquake forms were received (from the Meteorological observers at Quetta and Jacobabad) and five weeks had elapsed before I was able to visit the scene of the calamity, during which time a considerable amount of excavation among the ruins, and even rebuilding, had been done. Outside Baluchistan and the immediately contiguous portion of Sind the shock does not seem to have been felt. My cordial thanks are due to Sir Henry McMahon and Major Jacob of the Baluchistan Government, Mr. H. C. Dobbs and Mr. A. N. L. Cater of the Sibi Agency, Major McConaghey of the Kelat Agency and Mr. W. Beechey, Executive Engineer of the North Western Railway, for much information and assistance.

The data for the present account, apart from those given by the above gentleman, were collected during a fortnight's tour over the area

¹ Griesbach, *Rec. Geol. Surv. Ind.*, XXVI, p. 57; McMahon, *Q. J. G. S.*, p. 291, (1879); McMahon, *Geog. Journal*, IX, p. 402, (1897).

in which damage had been done, an attempt being made to visit and examine every village in it.

Owing to the scattered distribution of the population and their comparatively uneducated character, and above all to the total absence of Europeans from the damaged tract, verbal information of the type usually asked for on earthquake forms was found to be of little use, and personal observation of actual wrecking was practically entirely relied on.

In the hilly tract surrounding the Kachhi plain, no attempt was made to collect information or draw isoseismals (except in the southern part of the Bugti hills east of Shahpur), as here the population is still scantier and less civilised, and small earthquakes are of such frequent occurrence as to call for little notice from the inhabitants. In the hills no damage was done to property and the shock passed almost unnoticed except in Quetta. No reports were received from any seismological stations.

2. GENERAL ACCOUNT OF THE SHOCK.

Three time observations are available. The Meteorological Observers, at Quetta and Jacobabad both give 5-12 A.M. as the time of the shock, while the Bellpat station clock stopped at 5-7 A.M. The distances of these places from Bellpat, the epicentre, are respectively 96 and 56 miles, giving velocities for the vibrations of 0.32 and 0.19 miles per second, which are much too low, the average for the Kangra earthquake of the 4th April 1905, being 1.92 miles per second,¹ and for the Assam earthquake of the 12th June 1897, 1.98 miles per second.²

Obviously, then, the Bellpat time is unreliable, and the concordance, real or spurious, of the other two times deprives us of any means of estimating the velocity of propagation. At this early hour most of the victims and survivors were asleep, but those who were awake, on railway duty or for other reasons, unite in testifying to the suddenness of the shock, a feature common to most large earthquakes.

As one of the intelligent Saiyads of Shahpur remarked, 'There was hardly time to raise ourselves on our elbows before the roofs began to

¹ Middlemiss, *Mem. Geol. Surv. Ind.*, XXXVIII, p. 291.

² Oldham, *op. cit.*, XXIX, p. 70.

fail.' In cases where houses collapsed, none of the inmates seem to have had time to effect an exit before the roofs began to give, and escapes were due to protection by beams and to the fact that the roofs and walls often fell in sections.

Regarding the number of shocks and the duration of the vibrations there is considerable diversity of testimony. Sir Henry McMahon, at Quetta, considers that two distinct shocks occurred, the vibrations being continuous between and lasting altogether about 45 seconds. With this opinion Major Jacob and Major McConaghey agree, while the Meteorological Observer mentions one shock only, of 10 to 15 seconds' duration.

In Sibi three shocks were felt, but the duration is given by several Indian observers as three or four minutes, and at Mittri five to six minutes! At Jacobabad the Meteorological Observer detected three shocks, the first lasting 40 seconds, the second and third (probably after-shocks, as he mentions two times, 5-12 A.M. and 6 A.M.) very slight.

Regarding sound, there is a still greater difference of opinion, due in part to the lesser sensitiveness compared with Europeans, of many Indians to sounds of very low note, and to the obscuring din from local causes, such as slamming of doors, cracking of roofs, etc.

It is variously described as 'sound as if hundreds of persons running with shoes fast over roof,' 'cracking sound,' 'like guns,' and many witnesses are positive that they heard no warning sound. However, preceding several of the aftershocks a noise like the distant report of a single cannon (without reverberations) is said to have been heard, and while I was in Shahpur I heard three such, coming from the uninhabited desert to the N.W. of Shahpur, one of which at least was followed by slight vibration lasting for three seconds. The other two happened while I was on a riding camel, a situation in which an earthquake of considerable severity might pass unremarked. We may fairly conclude therefore that in the epicentral tract and its immediate neighbourhood the shock was preceded by a sound of low note, like the report of a heavy gun.

Anything approaching a complete record of aftershocks is naturally impossible in the absence of competent observers, but a certain amount of information has been collected from Bellpat, showing that for the period from the 21st October to the 31st, 76 shocks were noticed, and from the 1st November to the

Number of shocks and duration of vibrations.

The sound.

Aftershocks.

14th, 14. In one of these, at 2-30 A.M. on the 1st November, a woman was killed at Jalal Khan, a village 18 miles from Bellpat and well outside the epicentral tract. In Bagh and Shahpur, up to the time of my visit early in December, tremors were of almost daily occurrence, and often took place three or four times a day, as described above. A number of shocks have been reported from other villages, decreasing in number as we pass outwards from the centre of disturbance until we reach regions (in the hills) where it is doubtful if they have any connection with the Kachhi earthquake, but in all probability arise from independent strains. In the epicentral tract aftershocks were felt with diminishing frequency up to April 1910, the latest date of which I have information.

3. THE ISOSEISTS.

On the accompanying map are shown the three isoseists which have considered it advisable to insert without putting too great a strain on the data.

In these curves the Rossi-Forel scale of intensity has been adopted in preference to the Omori scale, as being more suitable for an earthquake of moderate intensity than the latter, the higher grades of which include surface intensities much in excess of that met with in the present case. In using the Rossi-Forel scale an allowance has to be made for the difference between the massive but weak local buildings and the more substantial stone and lime structures for which the scale was designed.

In the area examined stone buildings are unknown, and lime mortar is infrequently used. In the smaller villages, inhabited mainly by agriculturists, and in the meaner portions of the large villages the houses, one-storeyed as a rule, have their walls of mud (*gam*), built together in a pasty state, or of flat sun-dried bricks (*sil*), set in mud as a cement.

The roofs are of branches, with or without a layer of mud, or of wooden beams carrying reeds or matting, on which is laid mud some six inches thick. In the larger villages there are numerous mosques and two or three-storeyed houses belonging to zamindars and prosperous traders. These are constructed of burnt or sun-dried brick in mud mortar, plastered on the faces of the walls with mud and having very heavy roofs of mud on reeds and rafters. Walls of compounds are

generally of simple mud. The railway buildings are a most heterogeneous assortment of styles, but are all one-storeyed. Perhaps the most usual is of burnt brick walls laid in mud or lime mortar of poor quality, the roofs having old rails or wooden beams as rafters, on which lie thick brick tiles covered with mud on the outside. Reeds are sometimes used instead of tiles. Variations on these methods of building are sun-dried brick walls, corrugated iron roofs or roofs of sleepers laid close together, and huts constructed of a framework of sleepers or rails in which are built up panels of sun-dried brick or mud. For certain temporary huts about railway stations, and also here and there in villages, *sirki*, i.e., screens of matting with or without mud plaster, have been used.

It is evident from the absence of the slightest damage to the permanent way of the railway, or fissuring of the earth's crust (apart from gravitational slips of alluvium), that the maximum intensity of the shock was not so great as X of the Rossi-Forel scale. The next grade, IX 'partial or total destruction of some buildings,' seems to fit the case of the epicentral tract fairly well, if we admit that the comparatively incoherent and inelastic walls of the local buildings, coupled with unusually heavy roofs, have increased the effects to the total destruction of all but one-storeyed buildings. Outside this, in the area between isoseists IX and VIII ('fall of chimneys, cracks in walls of buildings'), practically all walls have been cracked, numerous parapets and isolated walls have fallen and a few roofs of poor construction have collapsed. In India, damage to buildings is considered to begin at grade VII,¹ and within this zone falls of plaster and cracks in buildings are numerous, without really serious damage having been done.

In any case an intensity scale founded on such variable factors as damage to buildings is at the best an empirical approximation, in which any modifications tending to uniformity of standard are preferable to a strict adherence to details.

Isoseist IX.

As shown on the map, this curve is an elongated oval, in area about 450 square miles, with its longer axis running in a N.W.-S.E.

¹ Middlemiss, *Mem. Geol. Surv. Ind.*, XXXVIII, p. 302.

direction. It embraces the two large villages of Bagh and Shahpur, the railway station of Bellpat and several small villages.

Perhaps the most striking fact to note is that the railway line traversing the area was absolutely undamaged, as were also the telegraph line and the iron water-tanks carried on tall rail frames. In the latter case there was no sign of vibration, even where the rail columns were bedded into brickwork foundations.

In striking contrast is the havoc wrought to the station buildings and bazar of Bellpat, to which the mortality, 26 out of a total population of 235, is sufficient testimony. It is noteworthy that 25 of these deaths were in the station buildings, one only in the bazar, a convincing proof that in point of safety the low mud huts of the latter, with mud on matting or branches as roofs, were much preferable to the better built, but really incoherent, Government buildings. In the bazar every house was damaged, but many were still habitable and, so far as I could judge, most of the havoc had been caused by the infalling of roofs, carrying with them walls, or parts of walls, rather than by the original collapse of the walls themselves. In the railway station the only buildings left standing were the outhouses of the Rest House and one block of employés' quarters (built last year). These were of burnt brick, as was also the office on the platform, which however had lost its roof. All other buildings, of whatever construction, were wrecked, only a wall here and there being left.

Regarding the direction in which buildings fell, no general rule could be established. At the time of my visit wreckage had been largely cleared up, unsafe walls demolished and old materials collected preparatory to rebuilding. The evidence of eye-witnesses of the collapse is most conflicting and nothing definite can be deduced.

Passing now to Bagh, as the north-west extremity of the epicentral tract, we have to consider a village of quite a different type. It is much larger than Bellpat, having a population variously estimated at from 1,500 to 3,000 (I should say more probably the latter), and had numerous mosques and fine two-storeyed buildings. These are constructed of both sun-dried and burnt brick of the local tile shape, and the smaller huts are of mud. The usual roofs are of mud laid on matting, or in the better houses, of mud on reeds, in both cases of course supported by heavy beams. The Tahsil

and one or two new houses and a few mud huts are all that remain unwrecked, and they also are much cracked.

There seems to be no appreciable difference in the resisting power of raw and burnt brick, but mud huts have stood better, when kept in good repair, a circumstance due probably to their lesser height and greater homogeneity. No system was observed in the direction of cracking or the way in which houses had fallen; the whole seems to have collapsed like a house of cards.

Though the proportion of Mahomedan inhabitants to Hindus was two to one, the respective deaths in these sections of the community were 29 and 37, giving a mortality rate for the Hindus two and a half times that for the Mahomedans. This is attributable to two causes, the first that Hindus are said to sleep indoors more than Mahomedans and so have less chance of escape; the second that the Hindus are mainly of the *bania* (shopkeeper) caste and are therefore in general more prosperous than their Mahomedan neighbours and can better afford two-storeyed houses; these suffered more severely.

Shahpur, a village of about the same size as Bagh, near the other (S.E.) end of the epicentral tract, presented an aspect of melancholy desolation. I am told that before the earthquake, its tall houses and splendid mosques were visible for miles around. Now it is a heap of ruins, made still more forbidding by its situation among lifeless sandhills, in the hollows of which the inhabitants had pitched their miserable shelters of reeds and branches. Of its three hundred houses not one remains and even the thick clay walls of compounds have been levelled. The materials of the houses are mainly sun-dried brick and mud.

The same peculiarly high mortality among Hindus has occurred here. In a population about equally divided, 69 Hindus were killed as against 33 Mahomedans, a death rate approximately two to one.

At the time of my visit the ruins had been considerably disturbed by the villagers in their search for their valuables and their dead, so I personally could make few reliable observations of the direction in which objects had fallen; but I am credibly informed that when able to fall freely, the buildings had done so to the north-west, showing that the shock had come from somewhere in the direction of Bellpat.

A very large tomb (Saiyad Hasan's), some five miles west of Shahpur, well built of burnt brick in plaster mortar and covered with glazed tiles, has fortunately suffered little. A good deal of the fine tile work has fallen, along with the pinnacles, but its sound construction has saved it from serious injury. The pinnacles fell towards the north, a direction consistent with the Shahpur observations.

Smaller villages. The smaller villages of the epicentral area are situated mainly in the Nari, Lehri and Belab river tracts, and these, with the crossing-station buildings along the railway north and south of Bellpat, may be described generally. In these villages mosques as a rule are wrecked, being the highest buildings and built of brick. The houses, small huts with mud walls and roofs of branches, and mud, lighter than is customary in larger villages, are usually all damaged and one-fifth or more have fallen.

Muradwa. At Muradwa, near the centre of the affected area, every house is wrecked and even shelters of brushwood have been thrown to the ground, the most violent manifestation of the shock met with.

The railway huts, mostly frames of sleepers filled in with brick or mud, were wrecked, while corrugated iron sheds were quite uninjured.

From these villages 20 deaths are recorded.

Slips of alluvium and surface cracks. In most of the river-courses flowing through this area, small falls of soil have taken place from the steep, almost overhanging, banks. In the dry bed of the river above the tank at Bagh, water oozed up in several spots. It was very bitter and has left an efflorescence on the surface. Good water is said to lie at a depth of fifteen feet, with bitter water below it so the earthquake must have disturbed the lower stratum. Here the river runs north and south, with a shelving bank on the east side, which, from the top of the bank to near the bottom, has moved bodily downwards, covering to the extent of a foot or two some cultivation on the flat below. The slipping has given rise to two systems of cracks, one set running close together along a steepish part of the bank for some fifty yards, in a direction parallel to the river. They are about six inches wide and are numerous, forming a band of fracturing two or three yards wide. The other set are smaller and less numerous, not more than an inch wide, and run up the bank perpendicular to the main group. The plane of sliding has probably been moistened by the water exuded from below.

facilitating motion. Farther downstream, where the shelving bank is found on the west side, the same thing is seen (Plate 4).

Around Shahpur are patches of clayey ground about the bases of the sandhills. These are seamed with zig-zag cracks, having a fairly persistent average trend of N. to N. 20° E., with branches and some cross-cracks. They are one or two feet apart, $\frac{1}{8}$ inch to $\frac{1}{4}$ inch wide, and the vertical displacement, if any, is only $\frac{1}{4}$ inch and is not in any definite direction, as if the cakes of clay had been shaken about at random. The cracks are approximately parallel to the direction the seismic vibrations have probably taken.

Here also the falling of precipitous stream banks is general, and the hummocks of hardened and wind-sculptured argillaceous sand, so frequently found among drifting sand-hills, are cracked and broken in all directions. East of Shahpur, in the extreme south of the Bugti hills, is an expanse of hillocks of incoherent and obscurely stratified clay and gravel, mapped as Upper Siwaliks. Their steep and unstable slopes are scored by innumerable small surface slips.

Two small rock-falls took place on the railway line at the ends of the Nari Gorge tunnel, a locality falling within grade VI of the scale, and far outside the area of damage. The rock-slopes here are so extremely unstable that slips cannot be taken as evidence of any considerable disturbance.

No resemblance to a "fault-cliff" of even minute dimensions was seen, though nothing could be better adapted for its preservation than the hard and level surface of the 'pat' desert.

Isoseist VIII.

The area within the next isoseist, grade VIII, is about 1,550 square miles, and its shape is almost exactly that of isoseist IX. In it there are no villages of the size of Bagh or Shahpur, but a fair number of smaller ones, several having good mosques and two-storeyed houses, which, as usual, have suffered more than the smaller buildings round them. As a rule in this tract few houses have actually collapsed. Here and there a roof or a gable has fallen, parapets and pinnacles of mosques have frequently gone, and cracking of walls is general.

It was exceptional to be able to discern any general method in the way in which houses had cracked or objects had fallen, and, when it was possible, in only two cases out of three did this agree approximately with the local direction of vibration, assumed to be parallel to the isoseists. (Theoretically the direction of cracking should be parallel to the wave-front, and the direction of falling perpendicular to it.)

In this area also the most seriously damaged houses are the composite ones of sleepers and brick or mud, used as gang-huts and crossing-stations on the railway.

As an example of the variety of the degree of damage which may occur in a single village, take the case of Katlar, near the outer margin of this isoseismal area.

A large three-domed mosque of burnt brick in mud mortar, almost completed by the Sirdar of the village, had lost two domes and was badly cracked. The top portion of a new and very high house of burnt brick had been shattered, and one of its gables had fallen. On the other hand, another fine mosque five years old was damaged only to the extent of a single pinnacle, and another high house, of raw brick, fifteen years old, was scarcely cracked. The small houses and walls in the village are practically uncracked.

Isoseist VII.

Within the next isoseist, grade VII, is included an area of 2,200 square miles, and its shape is the same as the two above described. Only a house here and there has been badly damaged, usually by a roof falling in or by the collapse of an arch. Mosques have occasionally lost their pinnacles and roof parapets have fallen, through the sagging of the roofs round which they are built. Cracking is by no means general, and has taken place in positions of weakness, such as the tops of arches and the junctions of walls.

Haji, a large village at the north-west end of the area, has suffered with exceptional severity, for some local reason unexplained. Practically all the houses are cracked, and fifteen or sixteen have fallen, including the dome of the mosque. Seven people were killed. It is noticeable that corners and gables of

houses on the northern side have suffered most. Outside this line evidence was but scanty and largely the testimony of untrained observers, but so far as it went showed a very gradual diminution of intensity.

4. THE FOCUS.

The most obvious feature of the epicentral tract is its great elongation in comparison with its width, betokening an origin in straight fault. from a straight line of faulting at no great depth and approximately vertical. There are some indications that the greatest intensity was to the north-west of Shahpur.

In finding the depth of the focus, the old method of intersection by drawing perpendiculars to the direction of the cracks in buildings, was found absolutely useless. The angles which the cracks made with the surface of the ground were found to be quite inconsistent and evidently depended more on slight inequalities of the buildings than on anything else.

In the method of Major C. E. Dutton, the depth of the focus is found by multiplying by $\sqrt{3}$ the distance from the assumed epicentrum to an empirical point where the intensity is considered to decrease most rapidly.

Two lines were fixed on, one between Lehri and Chachar, the other between Bellpat and Kokar, in the Lehri and Nari river tracts respectively, as in these, villages are frequent, comparatively speaking. On the first of these the required point seemed to be between 8 and 12 miles from the epicentre, giving a depth greater than 16 and less than 20 miles; in the second case, more than 6 and less than 9 miles from the epicentre, corresponding to a depth between 10 and 15 miles. For the Kangra earthquake Mr. Middlemiss calculates depths between 12 and 21 miles and between 21 and 40 miles. Comparing the areas included by the several isoseists in the Kangra and Baluchistan earthquakes, we are led to believe that the values given above for the depth of the latter's focus are probably as accurate as might be expected, but it must be admitted that outside isoseist VIII the intensity of the Baluchistan earthquake died out with very much greater rapidity than that of the Kangra shock, from which it would appear that my estimate is too large.

| Isosceist. | Area contained by isosceists. | |
|------------|-------------------------------|------------------|
| | Kangra. | Baluchistan. |
| X. | 200 sq. miles | ... |
| IX. | 1,600 sq. miles. | 450 sq. miles. |
| VIII. | 2,150 sq. miles. | 1,550 sq. miles. |
| VII. | ... | 2,000 sq. miles. |

5. INTENSITY ; ACCELERATION OF WAVE PARTICLE.

Unfortunately no measurements could be made of the acceleration, amplitude, velocity, or period of the wave particle. The region affected was quite devoid of seismographs.

Observations of overturned or projected objects could not be made in the total absence of suitable cases. When pinnacles of mosques, walls or parapets had fallen, they had been smashed to fragments ; had they been intact their intricate form and heterogeneous composition would probably have vitiated any results. Objects such as pillars or tombstones are unknown. Had I been on the spot earlier, the tall earthen urn-shaped grain-bins of the villagers might have yielded results, but these, when unbroken, had been re-erected.

6. EFFECT ON WATER SUPPLY.

The earthquake seems to have had little effect on subsoil water. At Kalandrani, a small village with three wells, near Shahpur, two of the wells had fallen in and the yield of the third was said to have become less.

It is reported that the 'Karez' water-supply of the Mastung valley has increased since the earthquake, but Mastung is so far from the point of origin, and the other effects of the shock were so slight there, that it is extremely doubtful if there is any connection between the phenomena. The uprising of water from the river bed at Bagh has been mentioned above.

7. GEOLOGICAL CONDITIONS IN RELATION TO THE EARTHQUAKE.

In a case like the present, where the earthquake area is so completely covered by thick alluvial deposits, any discussion of the cause must be little better than conjecture guided by probabilities.

A glance at the map suggests a relation to one of the most striking features of Indian geography, the gigantic festoon of the Marri and Bugti hills, by which the north and south trend of the Baluchistan ranges is interrupted, a feature which in its topography faithfully reflects the geological structure.

In a region of compression like this, so abrupt a flexure in the axes of folding must be the seat of special local stresses differing in character from the normal, and of a greater degree of severity.

Assuming that the epicentrum is a straight line, the trace of a fault running medially along the area of maximum disturbance, we see that towards its south-eastern extremity it is parallel to the nearest ranges there, and, therefore, in this case, parallel to the axes of folding.

Following it along to the north-west, we find that, if produced, it would meet the ranges between Dadar and Sanni at a high angle, about 80° . Thus it commences as a strike fault and continues as such until it is cut off by the abrupt southward sweep of the Kirthar range, or the strata parallel to the range, which no doubt flank it for some distance out under the alluvium.

The probability is that it is a reversed fault, since such faults more usually follow the strike than the dip, and since this is a region of compressive mountain elevation, in which thrusts predominate over normal faults.

8. THE EARTHQUAKE IN RELATION TO BUILDING METHODS AND MATERIALS.

At an early stage of the investigation it became evident that the main contributory cause of the great mortality, a total of 231, was the unusually heavy mud or tile roofs. The beams carrying these are built into incoherent, though thick, walls of mud, or what is even worse, bricks set in mud mortar. The inertia of the roof under oscillation had at once produced a line of division right round the walls at the point where the beams were inset, and the ensuing sagging of the roof showered down loosened tiles and cakes of clay on the interior.

As in all earthquakes, structures had suffered in proportion to their height.

No difference was observed in the resistive powers of sun-dried and burnt brick. Both these seemed to be inferior to simple mud, though comparison is difficult to institute, seeing that the latter is seldom used for any but one-storeyed houses. The fault of brickwork probably lies in the low quality and lack of tensile strength of the cementing material used and in the great temperature variations locally experienced, leading to disruption through expansion and contraction. Structures of burnt brick in lime mortar of decent quality stood well; still better were those of metal, for example, the water-tanks on the railway, and corrugated iron sheds. Where brick panel walls were used in combination with a metal or wood framework the results were disastrous.

Recommendations as to styles to be adopted in rebuilding are generally useless, save in the case of public bodies. Among Mahomedans an earthquake is regarded as an act of God, to guard against which savours of irreverence; by all classes it soon comes to be looked upon as a disagreeable experience unlikely to happen again, and in time custom and convenience overcome the dictates of prudence.

That houses should be one-storeyed is obvious.

Thick roofs are necessary as a protection against the heat of summer in this land, the hottest probably in all India. Still an endeavour might be made to use more thatching material and less mud or to have double roofs with an intermediate air-space. The roofs of heavy tiles adopted in many of the railway houses are most dangerous.

LIST OF PLATES.

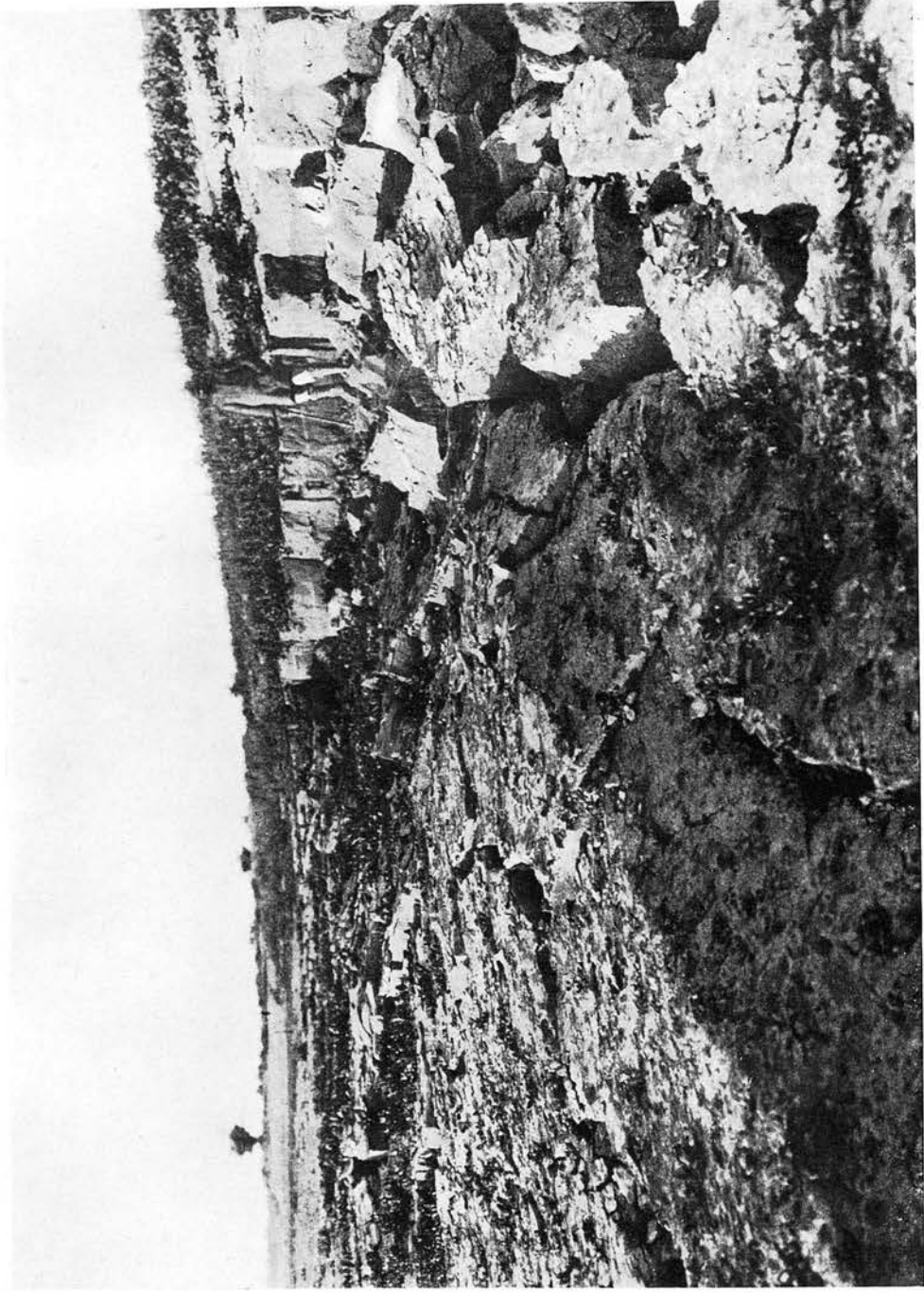
PLATE 4.

Slip of alluvium on river-bank at Bagh.

PLATE 5.

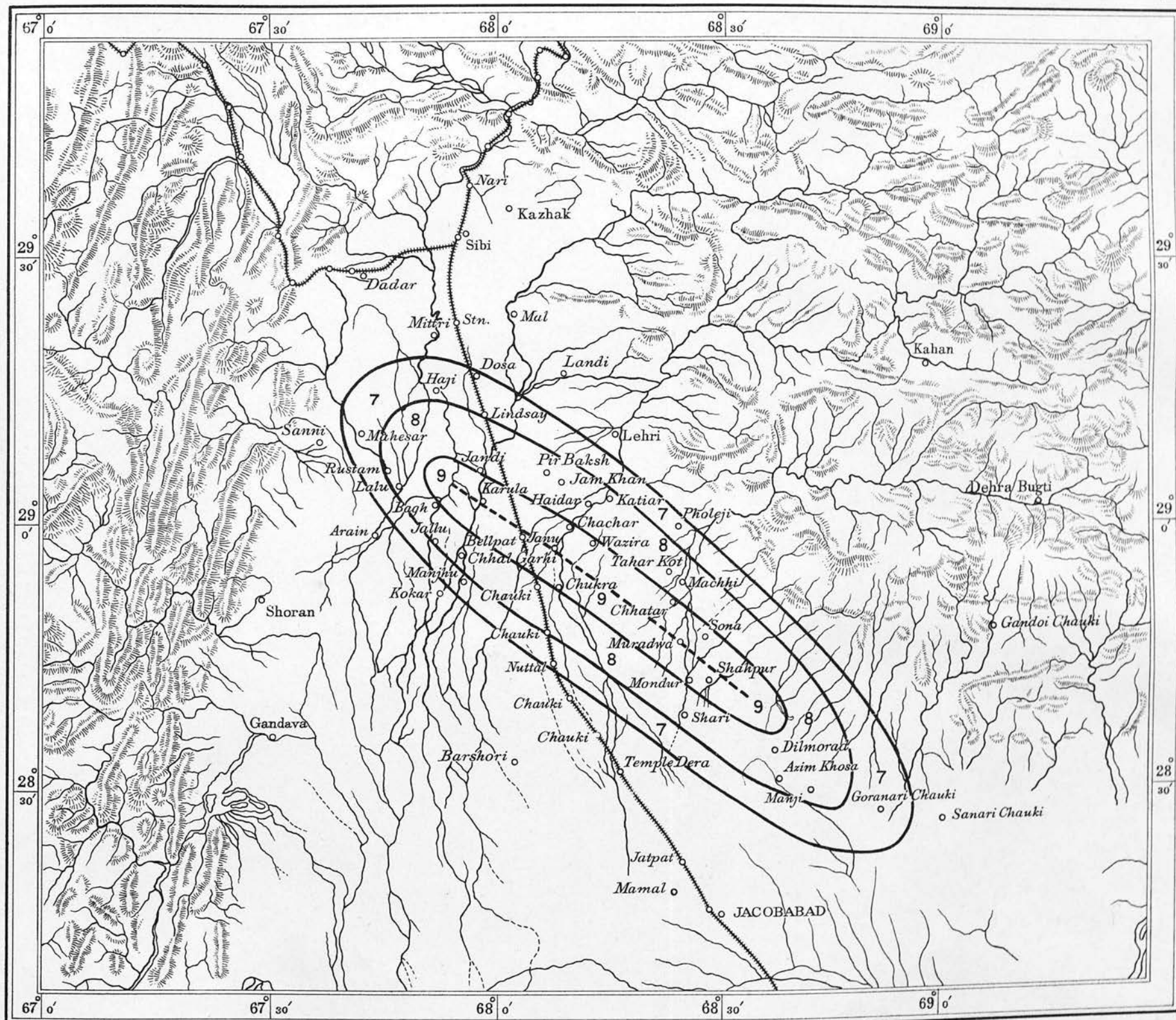
Map shewing Isoseismals of the Baluchistan Earthquake of October 21st, 1909.

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A. M. Heron, Photo.

SLIP OF ALLUVIUM ON RIVER BANK AT BAGH.



ISOSEISMALS OF THE BALUCHISTAN EARTHQUAKE OF OCT. 21st., 1909.

Scale, 1" = 16 miles.

To

With the Author's compliments.

Paper submitted in addition to Thesis for the degree of D.Sc.

THE KIRANA AND OTHER HILLS IN THE JECH AND
RECHNA DOABS.

BY

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(With Plates 21 and 22.)



THE KIRANA AND OTHER HILLS IN THE JECH AND RECHNA
DOABS. BY A. M. HERON, *Assistant Superintendent,
Geological Survey of India.* (With Plates 21 and 22.)

I. Introduction.

Until my visit at the end of 1909, these isolated hills had
not been examined by any geologist, save for
Previous observer. a reconnaissance, a day's stay only, by Dr.
Fleming in 1852.

The account given in the "Manual of the Geology of India" (p. 72) is taken from his description.¹

The hills rise from the level and, but for recent irrigation, arid
expanse of the Punjab alluvium in four separate
Situation. groups at Kirana ($31^{\circ} 58'$, $72^{\circ} 45'$),
Chiniot ($31^{\circ} 43'$, $73^{\circ} 2'$), Sangla ($31^{\circ} 43'$, $73^{\circ} 25'$) and Shahkot
($31^{\circ} 34'$, $73^{\circ} 32'$).

The first mentioned is between the Jhelum and the Chenab
rivers (the Jech or Chaj Doab), the Chenab flows through the
second group and the third and fourth lie between the Chenab and
the Ravi (the Rechna Doab).

They thus extend in a direction from north-west to south-east
over some sixty miles.

Of these, the Kirana Hills are by far the most important; there
is a diminution in the extent and the height of the outcrops as
we pass to the south-east.

Though only forty miles distant from the Salt Range, the rocks
are totally different from any occurring there
Topography. and approximate in character more to those
of the Aravalli Hills, the nearest point of which is 260 miles to
the south-east.

Apart from the isolation of their situation and the steepness
with which they rise from the alluvium, they present a remarkable
appearance in their bareness of vegetation and the sharpness of their

¹ *Jour. As Soc., Bengal*, XXII, p. 444.

peaks. Though the hill masses are elongated in the direction of the strike, they are lines of shattered, serrate summits rather than ridges.

Another feature, specially noticeable in the Kirana group, is the blackness of the hills as seen from a short distance away. The individual rocks are not particularly dark when freshly broken, but all long-exposed surfaces are coated with a thin, black, shining film of iron oxide, drawn up in aqueous solution through interstices by the sun's heat, and which the scanty rainfall is inefficacious in removing. This gives a great similarity in appearance to the exposures, aided by the close and splintery jointing of all the beds, resulting in a uniformly rugged and irregular aspect in which differences of stratification tend to be obscured.

Below the hard crust the rocks are rotten and break easily under the hammer into earthy and friable fragments. They are copiously impregnated with hæmatite.

In spite of the high inclinations at which the strata lie, no signs of schistosity were seen, even the slates are barely cleaved.

The metamorphism has been chemical and not dynamic; it has been caused by chemical rearrangements among the minerals of the rocks more than by heat and pressure developed in folding.

The highest summit is that of Kirana, which gives its name to the group, 1,662 feet above sea-level, or 1,050 feet above the level of the plain. The top of the hill is the site of a tomb and a large settlement of *sadhus* and is a popular place of pilgrimage, its distinguishing peculiarity being that every visitor is presented with something to eat.

Sangla is identified with the Sangala visited by Alexander the Great. The expanse of brick ruins is a marked contrast to the modern town, a busy market centre of a thriving canal colony, suggesting the mushroom cities of the Far West more than the slowly moving East.

II. Description—Kirana Hills.

These comprise a large number of very irregularly shaped rock masses, mostly elongated in a direction N.W.-S. E., coinciding with the strike. Dr. Fleming gives the strike as N.E.-S. W., but this is so only in the north-east arm of Kirana Hill, which, with part of Chinl-

wala Hill, would appear to be the vestige of one limb of an anticline, the other limb including the remainder of the hills in this group.

Dips are high and variable in amount, ranging from 40° to verticality, and, with the exceptions just indicated,

Dip.

are to the south-west. Sections are clear, but owing to the separation of the hills from one another by spaces of alluvium, are partial and discontinuous. Throughout the hills the predominant rocks are hardened shales or slates and rather argillaceous quartzites, coarse and fine.

The shales occur chiefly north-east, and the quartzites south-west, of a line passing midway through the

Shales and slates.

hills; the two zones are not sharply differentiated, but are still broadly separable.

As a whole the rocks are thin-bedded and, as one passes across the strike, are seen to vary constantly almost every yard.

The shales (23·9, 23·15; 7564, 7570) are usually green or grey, much impregnated with ferruginous matter along the bedding and the numerous joints.

The quartzites are harsh in texture, and grey, purplish or reddish in colour. They also bear much iron disseminated, and segregated near cracks. (23·13,

Quartzites.

23·21; 7568, 7576.)

From the angularity of the constituent grains and absence of bedding in some of the types which resemble

Tuffs.

quartzites in hand specimens, it is highly probable that some of them are altered tuffs. This is particularly so in Ghawala Hill. (23·6, 23·11, 23·33-4; 7561, 7566, 7588-9.)

Besides shales and quartzites there is a great development of thin beds of igneous rock, both acid and

Igneous rocks.

basic. In the field these, particularly the acid types, are with difficulty distinguishable from the quartzites, and even under the microscope the structure can only now and then be made out amid the copious secondary products into which the constituent minerals have weathered.

Discontinuity of outcrops and steepness of dip prevent individual beds from being followed far along the strike or dip, but there is every reason to believe that the acid rocks are effusive. In the case of the basic bands, two instances of inferred intrusion were

seen, but in general the basic bands also lie in parallelism with the rocks above and below. On the accompanying map I have indicated the occurrences of basic rocks and also some of the more distinct beds of rhyolites and tuffs. There are probably many more (rhyolites and tuffs) unmapped, as I often found it impossible to distinguish between ordinary quartzites, tuffs and acid eruptives without preparing and examining a large number of microscope sections *pari passu* with my field work. This I had not the opportunity of doing at the time.

The basic rocks are usually green or reddish brown, taking their colour from chlorite or hæmatite, whichever predominates, and they vary greatly in their texture. (23·7, 23·8, 23·10, 23·12, 23·16, 23·18, 23·28; 7562, 7563, 7565, 7567, 7571, 7573, 7583.)

Under the microscope the original structure is often difficult to decipher, but in certain sections the outlines of plagioclase feldspars and irregular plates of augite can be seen, the latter sometimes enclosing the feldspars ophitically. The feldspars have been replaced by a fine mosaic of scaly quartz, muscovite and kaolin, the augite by chlorite, hæmatite and kaolin. Large crystals of leucoxene after ilmenite are present and magnetite in small grains. Calcite seems to have been largely removed and re-deposited in cracks and vesicles. Some of the specimens contain large crystals of quartz, presumably original phenocrysts. From the above considerations it is probable that these highly altered rocks represent basalts or andesites, dolerites and quartz dolerites.

The sedimentary rocks vary from coarse grits to clay-slates. The grains are of quartz and magnetite imbedded in an argillaceous and ferruginous matrix.

Microscopic structure of tuffs, etc.

In those which I consider to be tuffs, the grains are angular, in the normal aqueous rocks they are well rounded and the matrix is greater in amount than in the former. In one slide fragments of devitrified glass occur (7589). Tuffs and ordinary quartzites are not usually separable in the field. A curious point in connection with the tuffs is the number of small and very irregularly shaped cavities they contain, either empty, lined with hæmatite or filled with chalcedony. They doubtless represent the location of some mineral constituent which has been removed in solution.

The acid effusives (23·17, 23·22, 23·23, 23·27; 7572, 7577, 7578, 7582) are classifiable as rhyolites. The **Acid igneous rocks.** phenocrysts are quartz and orthoclase, irregular and sub-angular in outline, the latter much kaolinised, and flocculent, brown, slightly pleochroic scales which are probably the remains of biotite. Green chlorite of similar origin also occurs. The cryptocrystalline base is usually vesicular and yellow in colour. Certain of the bands are devoid of phenocrysts, obsidian (23·14; 7569) and traces of spherulitic structure were seen.

Chiniot Hills.

These consist of a narrow broken ridge running west-north-west (the direction of the strike) across the course of the Chenab, which flows through the hills in a couple of picturesque gaps. They appear pale grey, red-mottled quartzites, alternating coarse and fine on the north side and slaty on the south, dipping at 40°-60° north-north-east. Under the microscope they are seen to be tuffs and volcanic agglomerates, consisting of angular fragments of quartz and devitrified glass in a dusty matrix. (23·33-4; 7588-9.)

Sangla Hills.

The Sangla Hills are composed of pale grey quartzites, (23·36; 7591) similar to the above but finer in texture and more abundantly stained with red and purple ferruginous matter. They are thinly and regularly bedded and dip east and south-east at high angles, with copious and rectangular jointing.

Shahkot Hills.

The rock of the Shahkot Hills is still more ferruginous, fine grained and argillaceous. (23·37-8). The strata dip north-east at somewhat irregular angles, 50°-70°, and are more cleaved and altered than most of the other rocks. An isoclinal anticline runs midway through the group.

III. Comparison with rock-types from other areas.

It occurred to me that in the boulder-bed of the Salt Range, an assemblage of widely differing rock-types, accumulated probably in Talchir times by glacial agency, there might be some representatives of the rocks of the Kirana Hills.

Salt Range boulder bed.

With this end in view I examined the material available in the collections of the Geological Survey, including a set of typical samples of pebbles from the boulder-bed, collected by Middlemiss.¹ The majority of these are in no way similar to the Kirana rocks, but in a few cases noted below the resemblance, though not amounting to identity, is enough to show that some of the rocks of the boulder-bed were in all probability derived from the area under consideration.

Boulder-bed.

Kirana.

| | | |
|------------------------------------|--|--|
| $\frac{8}{472}$, 656 ² | $\left\{ \begin{array}{l} \frac{23}{23}, 7587 \\ \frac{23}{23}, 7587 \end{array} \right\}$ | devitrified rhyolites with quartz and felspar phenocrysts. |
| $\frac{8}{480}$, 663 | $\left\{ \begin{array}{l} \frac{23}{23}, 7589 \\ \frac{23}{23}, 7581 \end{array} \right\}$ | coarse-grained tuffs (?) |

With regard to the Malani rhyolites³ and the felsites of Tusham,⁴ there is a reasonable likelihood that the rocks of these three widely separated areas are identical in age. Though my specimens from the Kirana Hills are much more weathered than the large series collected by La Touche, yet the general type is the same. This also appears to be the case when tested by the description of the Tusham felsites by McMahon. The Kirana and Tusham rocks agree in the presence of small amounts of biotite, rare in the Malani types. In their field relations the Malani rocks are associated with non-volcanic sediments to a much less extent than are the Kirana effusives (and the Tusham felsites as far as can be judged from the small exposure). This would seem to indicate that, passing to the north, the results of volcanic activity have diminished and the flows dovetail into ordinary sediments. This is confirmed by the vastly greater thickness of the separate sheets in the south, in the Malani area. At Kirana and Tusham dips are higher than among the irregularly and moderately undulating strata of Malani.

¹ *Rec. Geol. Surv. Ind.*, XXV, pt. 1, p. 29.

² The first numbers refer to hand specimens, the second to microscope sections in the Geological Survey collections.

³ Blanford, *Rec. Geol. Surv. Ind.*, X, p. 10.

Oldham, *Rec. Geol. Surv. Ind.*, XIX, pt. 2, p. 124.

McMahon, *Rec. Geol. Surv. Ind.*, XIX, pt. 2, p. 161.

La Touche, *Mem. Geol. Surv. Ind.*, XXXV, pt. 1.

⁴ McMahon, *Rec. Geol. Surv. Ind.*, XVII, p. 108.

The basic rocks of Kirana somewhat resemble the olivine dolerite dykes of Malani¹ except that olivine Malani basic dykes. is not recognisable in my sections. Alteration has proceeded so far however that this is no proof of its initial absence.

The quartzites and slates of Kirana bear a general family resemblance to the Ajabgarhs of North-Eastern Rajputana, but when dealing with groups of Ajabgarh slates and quartzites. altered sedimentaries in such widely separated areas, general resemblances are of little or no value in correlation, and it would be rash to base a statement of identity on evidence so imperfect. It is, however, probable that they belong to the Peninsular series rather than to the Extra Peninsular, and may be included in the Purana Group.

IV. Economic Chapter.

According to Dr. Fleming². "The sandstone" (*i.e.* slate of Kirana Hill) "is traversed by numerous veins of white Iron. quartz containing masses of rich hæmatite iron ore, which do not seem to have attracted at all the attention of the natives as a source of iron, although it can be obtained in considerable quantity and ought to yield from seventy to eighty per cent. of metal. Filling small cracks in the sandstone some small specimens of pyrolusite or peroxide of manganese were obtained."

During my examination I saw very few of these quartz veins and I am unable to agree with Dr. Fleming's optimistic view. Though the large amount of iron present as films filling cracks and as interstitial material is one of the most noteworthy features of the hills, nowhere is it present in such purity or such amount as to justify exploitation. Here and there slag fragments are seen, from the former operations of those wandering *lohars* (blacksmiths) who tour the plains of Northern India, but in their work cheap imported iron has long supplanted that locally extracted from ores laboriously hand-picked from over considerable areas.

Pyrrhotite has been recorded³ from Hundewali (Hoondiwala) Hill in masses up to one centimetre or more in diameter, scattered through compact grey-green Pyrrhotite.

¹ *Mem. Geol. Surv. Ind.*, XXXV, pt. 1, pp. 25, 91.

² *Jour. As. Soc. Beng.*, XXII, p. 446.

³ *Rec. Geol. Surv. Ind.*, XXXI, pt. 3, p. 174.

quartzite. It is magnetic, brass-yellow in colour and contains neither nickel nor cobalt. There must be very little of the mineral, as Mr. Hayfield, who had been in charge of the North-Western Railway ballast quarries at Hundewali for two years, informed me that he had seen only one piece.

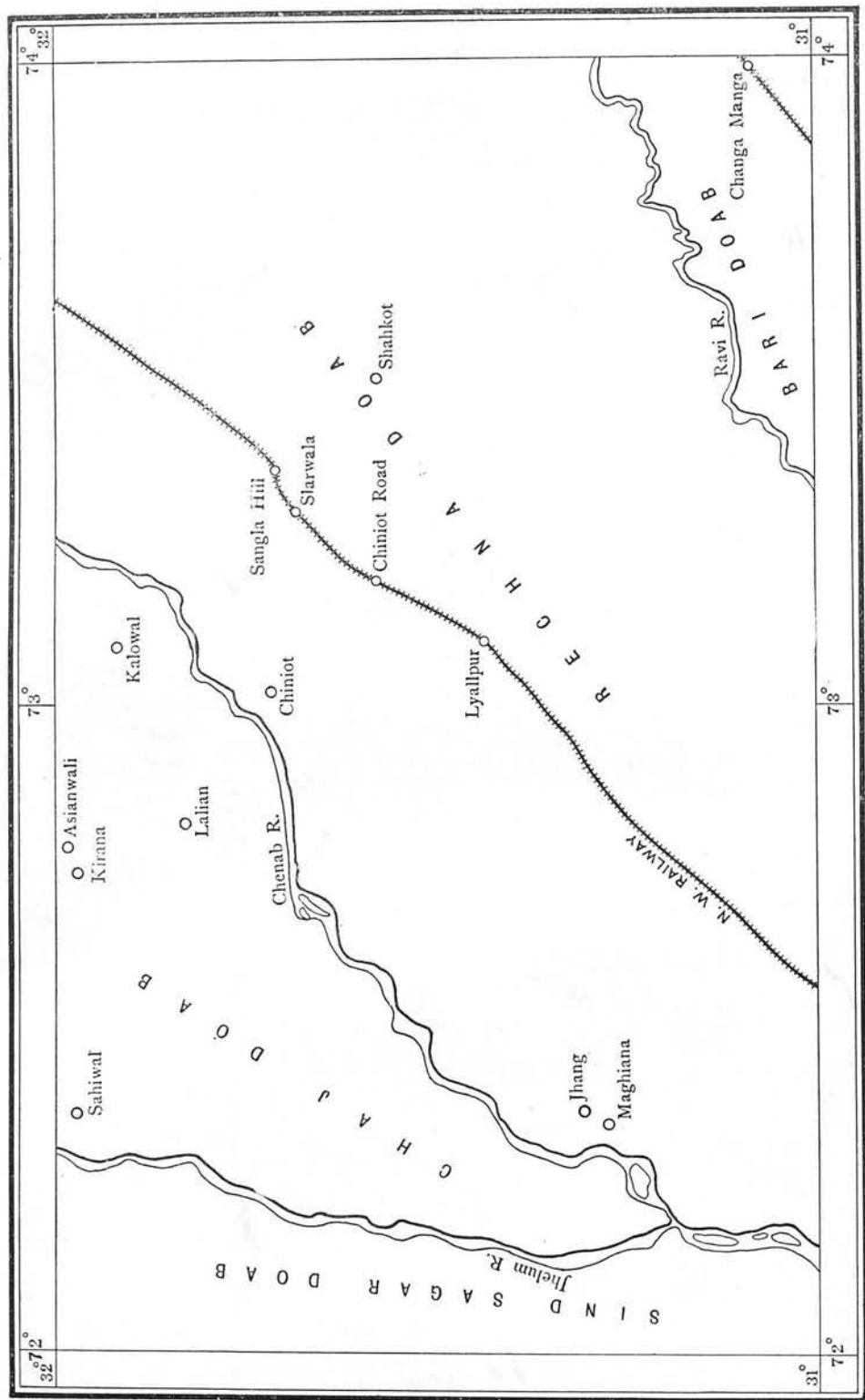
Hundewali and Sangla Hills are worked on a large scale by the North-Western Railway for ballast, and several of the others afford road metal.

Railway ballast.

EXPLANATION OF PLATES.

PLATE 21.—Sketch-map showing position of Kirana, Chiniot, Sangla and Shahkot. Scale 1"=16 miles.

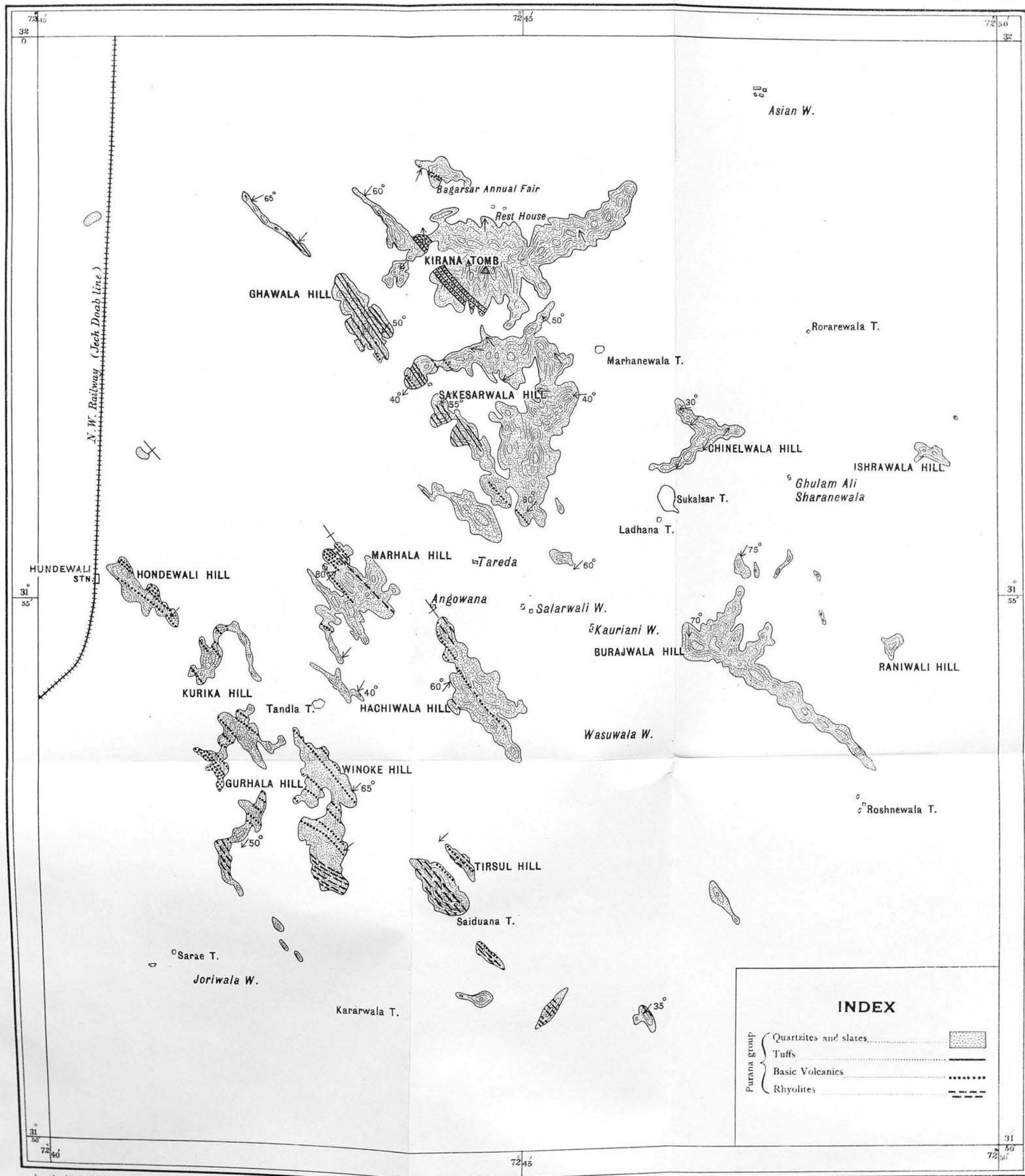
PLATE 22.—Geological map of the Kirana Hills. Scale 1"=1 mile.



by A. M. Heron.

SKETCH MAP SHOWING POSITION OF KIRANA, CHINIOT, SANGLA and SHAHKOT.

Scale, 1 inch = 16 miles.



by A. M. Heron.

GEOLOGICAL MAP of the KIRANA HILLS.
Scale, 1 inch = 1 mile.

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To.....

With the Author's compliments

THE BIANA-LALSOT HILLS IN EASTERN RAJPUTANA.

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(With Plates 9 to 12.)



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INTRODUCTION.

THESE hills form an area almost entirely isolated by alluvium from the extensive outcrops to the north, described in my memoir on the geology of North-Eastern Rajputana, and show in their stratigraphy and in the amount of folding, alteration and igneous intrusion, which the constituent beds have undergone, various important differences from the rocks of the same age in that region. To the south they are completely separated by alluvium, and by one of the two great boundary faults of Rajputana, here concealed by surface deposits, from the plateau of Upper Vindhyan rocks described in my account of the Gwalior and Vindhyan systems in Eastern Rajputana; at the eastern end of the hills, near Biana, this alluvium has a breadth of only four miles, and the scarps of the Alwar series and the Upper Bhander sandstone face each other across the narrow gap, giving from their proximity an excellent opportunity of comparing their distinctiveness in lithological composition, in the alteration and folding to which they have been subjected, in the topography to which they give rise and even in the amount and character of the vegetation on their surface.

Biana (Bayana) is the junction for the Agra branch on the Bombay, Baroda and Central India railway route from Bombay to Delhi,

broad gauge, and is the only point at which these hills are accessible by rail. The area is very conveniently divided into two sections, the Biana hills and the Lalsot hills, united only by a narrow ridge, Biana ($26^{\circ} 55'$: $77^{\circ} 21'$) being at the extreme east and Lalsot ($26^{\circ} 34'$: $76^{\circ} 23'$) at the west of the two sections, the two places being 63 miles apart. The total length of the hills, measured along their general north-east—south-west trend, is about 75 miles and their breadth 8 to 10 miles. Politically the Biana hills lie in the Bharatpur State and the Lalsot hills in the Jaipur State of the Rajputana Agency, and I would here acknowledge my indebtedness to Lieutenant-Colonel B. E. M. Gurdon and the late Lieutenant-Colonel H. L. Showers, who were then in political charge of these States, for assistance and facilities enjoyed during my work and for much personal kindness.

The geological survey of this area was carried out in March 1911 and January and February 1912, as part of the general revision of the Rajputana survey, under the superintendence of Mr. C. S. Middlemiss. Mapping was done on the Survey of India Standard sheets, 1 inch=1 mile.

In his two papers on the geology¹ of Rajputana Mr. C. A. Hackett has very briefly alluded to this tract, and my re-survey is a considerable amplification of his work, although based on it.

The formations which occur are two :—

- (a) the schists, granites and pegmatites of the Aravalli system and
- (b) the quartzites, conglomerates, shales and trap, belonging to the Alwar series, the lower of the main and persistent subdivisions of the Delhi system. The beds of the Delhi system rests on the Aravallis with a profound and exceedingly distinct unconformity and are folded into them, in the Lalsot hills at least, in a series of synclines, the intervening anticlines being as a rule worn down by denudation and the older rocks exposed along their axes.

The Raialo quartzite and limestone, which in the south of Alwar form a local subdivision of the Delhi system resting on the Aravalli system below the Alwar series, are here absent from the sequence, and the Kushalgarh limestone, the hornstone breccia, and the

¹ *Rec., Geol. Surv. Ind.*, Vol. X, 2, p. 87; *Rec., Geol. Surv. Ind.*, Vol. XIV, 4, p. 298.

Ajabgarh series, which normally succeed the Alwar series, are not seen, as none of the sections here extend upwards far enough to include them. They may be present in some of the synclines, but, if so, they are buried beneath alluvium, except in one doubtful case. As far as this area is concerned therefore, the terms Delhi system and Alwar series are synonymous.

The rocks of the Aravalli system will be described first, from the east of the area westwards, and then the Delhi system in the two geographical divisions into which it naturally falls, the Biana and the Lalsot hills.

Table of formations.

| GROUP. | SYSTEM. | SERIES. | STAGE. | — |
|-------------------|-----------------------|---|---|--------------------------------------|
| PURANA GROUP | Delhi system. | Alwar series | (Biana Hills only.) | UNCON- FORMITY. |
| | | | <i>Wer stage—</i> | |
| | | | Quartzites . . . 2,300 ft. | |
| | | | Shales . . . 300—400 ft. | |
| | | | Trap band. | |
| | | | <i>Damdama stage—</i> | |
| | | | Thin-bedded sandstones and shales . . . } 4,000 ft.* | |
| | | | Massive quartzites . . } | |
| | | | Conglomerates . . . | |
| | | | <i>Biana stage—</i> | |
| ARCHEAN GROUP. | Aravalli sys- tem. | Phyllites, quartzites, etc. Granites and pegmatites, intrusive in Aravalli system. | Quartzites . . . 1,100 ft. | UNCON- FORMITY DOUBT- FUL. |
| | | | <i>Badalgarh stage—</i> | |
| | | | Flagstones and shales . 600 ft. | |
| | | | <i>Nithahar stage—</i> | |
| | | | Quartzites . . . } | |
| | | | Tuffs, trap, etc. . . } | |
| | | | Quartzites . . . } | |
| | | | Basal conglomerate . } | |
| | | | | |
| | | | | |
| | | | | EPARCH- ÆAN UNCON- FORMITY. |

Aravalli System.

The outcrops of the metamorphic rocks belonging to this system, and of the granites and pegmatites intrusive in them, form a very narrow band, at the foot of the scarps of Alwar beds, which have protected them from entire removal, around the borders of the synclines. Although they disappear beneath alluvium at a very short distance away from these scarps, an enormous thickness of them is represented, for their strike is at nearly a right angle to that of the overlying Alwar beds (Pl. 10, fig. 1). In his earlier paper Hackett calls them the "Schist Series" and in his later paper puts them into the Aravalli system. It is of course impossible to prove that they are of the same age as the similar rocks, penetrated by similar granites, which occur below the base of the Delhi system in the south of Alwar, but there is every likelihood that they are of the same age. In the Biana hills they are found below the scarp of the Nithahar quartzite, the lowest division of the Alwar series, for a distance of about fourteen miles. In spite of the very great thickness exposed—for the narrow band of outcrop runs almost perpendicularly to their strike—they show little variation in their character. For the most part they are silvery, buff or reddish talcose phyllites, with bands of quartz-talc schist, and soft, rusty, argillaceous quartzites. The dominant strike is north-east or north-north-east and the dips high and irregular, varying to both sides of verticality. The band of Aravalli rocks and certain of the overlying stages are repeated by a strike-fault. The minimum alteration in the Aravallis is seen at Kondra ($26^{\circ} 57'$: $77^{\circ} 2'$), where the group of hillocks standing out on the plain in advance of the scarp is composed of indurated, very slightly altered, pale and dark-grey, thick bedded clay-rocks, not even slates, a great contrast to the schists of the same system to the west; and yet they are clearly overlain by the hard and vitreous, but much younger, Nithahar quartzite of the scarp. The very moderate alteration of the Aravalli rocks, as well as the comparatively gentle dips of the Delhi beds shows that this region has escaped the intenser plications of the Aravalli Range.

For a considerable distance along the base of the ridge connecting the Biana with the Lalsot hills, from Kondra to Morra ($26^{\circ} 49'$: $76^{\circ} 52'$), the Aravalli system is not seen, but the lowest Alwar beds exposed form a thick band of rock—similar to the Kondra clay-rocks

and evidently composed of their re-assorted débris—all the way along the foot of the scarp.

At Morra the Aravalli beds are olive-green and brown talcose phyllites and schists, more altered than those at Kondra. Farther west, at Kamalpur ($26^{\circ} 48'$: $76^{\circ} 49'$) they are mica-schists with pegmatite intrusions. The small outlying hills at Pahari ($26^{\circ} 47'$: $76^{\circ} 56'$) and Talchiri ($26^{\circ} 54'$: $77^{\circ} 5'$) are ridges of vertical, copiously jointed and quartz-veined quartzite, with, to the south of Pahari, a small outcrop of arkose grit, almost indistinguishable from granite, like which it weathers.

The Aravallis are not seen again to the south-west up to Lalsot, at the other end of the hills. At Lalsot they are mica-schists, resembling compressed grits, banded along the strike with medium to coarse-grained pegmatite in rough lenticles and streaks, twisted and pinched out irregularly¹. In places the schist is quite free from pegmatite, in others the pegmatite greatly predominates. The difference in strike between the beds of the Delhi and Aravalli systems respectively is very marked, that of the latter being constant in a north-east—south-west direction and that of the former curving from east-north-east—west-south-west to north-west—south-east. The junction is well seen immediately to the west of Lalsot; the pegmatite, locally unmixed with schist, is closely adherent to the basal bed of the Alwar series, a compact black vertical quartzite, with a line of pebbles of pegmatite and of vein-quartz at the contact. The quartz-veins from which the latter are derived traverse the pegmatite and are cut off sharply at the old denuded surface, projecting slightly from it by reason of their superior hardness, in the same way as do the aplite veins at Gisgarh (p. 186).

At intervals all along the north-western side of the long valley opening near Lalsot and extending up to Lalsir ($26^{\circ} 45'$: $76^{\circ} 39'$), pegmatite-veined Aravalli beds are seen; on the other flank no exposures are available.

The actual junction is almost always hidden by scree-material, but at the base of the scarps, from the opening of the valley, *i.e.*, its south-west end, as far up as Moran (Garh on the map, $26^{\circ} 43'$: $76^{\circ} 36'$), Delhi and Aravalli beds are seen almost in juxtaposition and agreeing in their general strike. There is, however, no doubt

¹ The detached hill at Chondias, four miles west of Lalsot, is of ordinary massive granite carrying veins of tourmaline pegmatite.

about the unconformity, as the pegmatite veins in the Aravalli rocks are all truncated on a horizon of conglomerates composed of pebbles of arkose and quartz, constituting the base of the Alwar series. Beyond Moran the base is more sinuous and is seen to cross the strike of the underlying Aravalli beds. It is curious that the felspar pebbles in these conglomerates are all salmon-pink or reddish, while the felspars of the underlying pegmatites are white, or at the most pale pink; this indicates that the conglomerates are not derived from material *in situ* immediately below, but from the massive granites to the north the felspars of which are strongly coloured.

The Rupali hill, 1 mile south-east of Garh, is composed of dark-rusty and vitreous quartzites, impure slaty limestones and amphibolites of the Aravalli system.

In the Gudho ($26^{\circ} 47'$: $76^{\circ} 43'$) valley, eroded along an anticline of the Delhi beds like the preceding valley and really a continuation of it but not on the same anticline (p. 197), granite is exposed at only two points within the inward-facing scarps. It is of the same type as the Aravalli granite of Parla¹; it is porphyritic, strongly biotitic and devoid of pegmatite veins, and has the phenocrysts distinctly arranged in lines.

In the Gisgarh ($26^{\circ} 53'$: $76^{\circ} 42'$) anticline, the Aravalli granite is more extensively exposed than elsewhere, with very clear sections of the unconformity. It forms a prominent irregular glacis below the scarp, which has at its base reddish quartz-mica schists with feldspathic layers, and locally, resting on the granite, a layer of fine conglomerate composed of quartz and felspar pebbles in a black matrix. The schists, it is clear, have originally been arkose grits derived from the disintegration of the underlying granite, and are now greatly compressed. The surface of contact of the granite is very even, a few veins of harder, aplitic material project for a few inches into the overlying grits, and broken-off portions of this lie imbedded in them, partially rounded but not transported to any distance from their place of origin. The two detached hills at Giltari and Karolian also show the unconformity well; at the latter place there is some amphibolite veining in the granite, doubtless connected with certain epidotic and calcareous slates in the overlying Alwar beds, which greatly resemble altered tuffs.

¹ *Mem., Geol. Surv. Ind., XLV, p. 19.*

Taking the Biana-Lalsot tract by itself, the relationship between the pre-Delhi granites and the Aravalli metamorphics is doubtful, for the two are never found in contact, but in the country to the west—southern Jaipur—granites of exactly the same type as the above were found to be clearly intrusive in Aravalli schists, so that in the present area there is every probability that the metamorphic rocks are the older and that the granites were intruded into them, and the whole complex was denuded before the beds of the Delhi system were deposited.

It has been seen that, proceeding from east to west along the range there is a progressive increase in metamorphism in the Aravalli sediments—accompanied by an increase in the amount of igneous intrusion—from phyllites and argillites to mica-schists injected with pegmatite, and unmixed granites. The overlying Delhi beds share in this, at least with regard to alteration, and its cause is that, going westwards, the core of the ancient Aravalli range is approached, where compression by folding, deep-seated metamorphism and igneous intrusion reach their maxima.

The Delhi system : *Alwar series.*

BIANA HILLS.

The Biana hills are peculiar amongst the areas of the Delhi system in the comparatively low dips of the beds throughout, 20° being about the average, and that here the Alwar series can be divided into several stages by unconformities and differences of lithological character. Hackett¹ has adopted five, to which I have adhered, (see Table of formations) and mentions one unconformity and several conglomerates indicating breaks in the succession.

The Raialo quartzite and limestone, a local division forming in Alwar the base of the Delhi system, below the Alwar series, is here not developed, and the beds above the Alwar series are, if present, concealed by alluvium, so that here and in the Lalsot hills the latter series is the sole representative of the Delhi system.

In the Biana hills the conglomerates are extremely variable and occur in force only at their eastern end and in the middle stages, the Damdama and the Biana, so are of little value in

¹ *Rec., Geol. Surv. Ind.*, Vol. X, 2, p. 87; *Rec., Geol. Surv. Ind.*, Vol. XIV, 4, p. 298.

correlation; Hacket in fact arrives at his divisions without taking them into account. All the stages, especially the Damdama, decrease in thickness from east to west, and the uppermost, the Wer stage, overlaps the three middle formations and is finally found in juxtaposition with, and apparently conformable to, the Nithahar stage. It is probable that, as well as an overlap, there is an actual dying out of the middle formations, as indicated by their visible diminution in thickness; to the west, however, the sections are unfortunately very incomplete. Hacket believed that the Nithahar stage also died out, the Wer overlapping it on to the Aravalli beds. In this I disagree with him, for I can find no evidence for it and the rocks of the ridge connecting the Biana and Lalsot hills, which he considered to belong to the Wer stage, resemble the Nithahar much more closely than they do the Wer.

As has been stated, in these hills the dips of the Delhi beds are much lower than is usual, being between 10° and 20° throughout most of their extent, but at the west end the strata gradually become steeper in inclination and concurrently more metamorphosed. Along the eastern two-thirds of their length the dips are to north-east and north-north-east, in the western third swinging round to north-west, and at the extreme eastern end also they dip to the north-west for a short distance.

In my memoir on the Delhi system in North-Eastern Rajputana,¹ I have suggested that the change in the character of the rocks of the Alwar series, as one passes northwards from the outcrop of their base on the Alwar-Jaipur frontier, from beds denoting littoral conditions to a facies of deeper water accumulation, is due to the derivation of their materials from a land area in existence somewhere to the south of their present southern margin there. In the Biana hills the great thicknesses of conglomerate, the considerable accumulation of tuffs and effusive lavas, and the unconformities and overlaps, are still more indicative of littoral and terrestrial conditions and of those oscillations of level which take place on a continental margin, and we may safely assume that the land area from which those sediments were derived was close at hand on the south or south-east. We know nothing of the distribution of the earlier Purana rocks or of the configuration of the pre-Delhi land-surface over the adjoining regions in south-eastern Rajputana and the major portion of Central India, for the Vindhya and the

¹ *Mem., Geol. Surv. Ind.*, XLV.

Deccan Trap cover all. It is possible that the apparent absence of the Delhi system over a large portion of central Jaipur (to the west and north-west of the present area) may be a real absence, due to the presence there also of a raised area or island at the time of their deposition,—a land-mass which supplied from its disintegration part of the materials for the beds of the Delhi system in Alwar, for those of the Lalsot-Biana hills and for the immense pile of conglomerates seen in the Lalgah hills to the north-west. It is significant that, from the scanty evidence we have, the locality of this hypothetical island is distinguished by the presence of granite to the exclusion of other Aravalli rocks, which is what we should expect, for a large granite boss naturally gives rise to high ground from its superior resistance to denudation as compared with the softer phyllites and schists. In Bundelkhand again we have exposed a vast granitic or gneissic area, which would be, on my assumption, a part of the other or main land surface around which the Delhi and succeeding Purana systems were deposited.

(a) *Nithahar Stage.*

The Nithahar stage is the lowest division of the Alwar series, and supervenes immediately above the Aravalli System. At the base is a conglomerate formed of imperfectly rounded pebbles of white quartz and fragments of the underlying Aravalli phyllites in a yellowish argillaceous matrix, also derived from the phyllites; the greatest thickness seen, about 10 ft., was observed at Nithahar, but along most of the junction it is very much thinner; evidently such soft rocks as the phyllites do not tend to the formation of conglomerates from their disintegration. The lower beds of the Nithahar stage are pale in colour, fine-grained and vitreous—quartzites in all respects typical of the Alwar series.

Near the middle of the stage are two zones of volcanic rocks, of which the upper is much the thicker, comprising numerous agglomerates, tuffs, vesicular traps and dark ferruginous quartzite—clearly the results of contemporaneous volcanic activity—, interbedded with quartzites. The bands are too thin and too numerous to be mapped individually. The traps are extremely tough, green, sparingly pointed rocks, often vesicular, and are none of them thick, nor does any thickness of them occur without intercalation of tuff or quartzite. Under the microscope they are seen to be highly altered mineralogically, but their crystals are quite undeformed. They

appear to have been dolerites, in which the laths of plagioclase are completely changed to saussurite and the augite to irregular masses of chlorite. Leucoxene is also present. There is none of the wholesale recrystallisation and formation of hornblende and secondary feldspars which are seen in the amphibolites of the same or younger age in the Delhi system elsewhere and which are due to folding and deep-seated metamorphism which these have escaped. The tuffs and agglomerates are composed of angular fragments of quartz and quartzite, with rounded greenish pieces of trap and green devitrified volcanic glass.

The lower volcanic zone is about 400 ft. thick, the upper about 1,600 ft. at its maximum development, but it dies out rapidly to the south-east. The total thickness of the Nithahar stage is some 3,500 ft. Above the volcanic beds the rocks are similar to those below.

Near Sita (Silagaon of the map, $26^{\circ} 59'$: $77^{\circ} 11'$) are several local conglomerate bands, one of them extremely coarse and very thick, and all copiously impregnated with iron-oxide in the cementing material in the interspaces, giving a dark purplish hue to the rocks. The pebbles in them include white vein-quartz, jasper rock, white, grey and black quartzite, and conglomerate, in a ferruginous matrix. No gneiss, granite or schist pebbles were seen.

About 2 miles west of Sita, two large dykes cross the strike the longest $1\frac{1}{2}$ miles long, of a soft, foliated, ferruginous quartz chlorite schist, the decomposition product of a basic dyke-rock. They are probably feeders of the lava flows, from the horizon of which they extend downwards.

As is to be expected from their nature and their lie, the beds of the Nithahar stage give rise to a succession of nearly vertical scarps backed by dip-slopes with a declivity of 10° - 20° .

West of Sita the Nithahar stage is topped by the Wer stage—their mutual relationship will be described when treating of the latter. East of Sita it passes up conformably into the Badalgarh stage; the actual junction is concealed by débris at the base of a bold cliff formed by the Badalgarh stage, a cliff which runs continuously through the hills, but there is no evidence to suggest an unconformity.

(b) *Badalgarh Stage.*

The Badalgarh stage forms a very distinct division, about 600 ft. thick, composed of argillaceous (sometimes gritty) flagstones

with shaly and micaceous layers. Being heterogeneous and easily eroded their preservation is due to the hard Biana quartzites capping the scarp and preserving its verticality. In a gorge, 1 mile south-east of Sita, is seen a local unconformity between the Badalgarh and the Damdama stages, the intervening Biana stage being overlapped (*v. infra*); elsewhere the Biana stage follows conformably on the Badalgarh.

(c) *Biana Stage.*

Hacket describes the Biana stage as "a white quartzite containing many bands of conglomerate," a rather misleading description, as the quartzites are all pink or pale reddish-purple and the conglomerate bands occur only at the extreme eastern end of the hills, dying out within a quarter of a mile. Like the other stages, the Biana has its maximum thickness, about 1,100 ft., at the east, thinning gradually westwards. It consists of pink and pale reddish-purple quartzites, fine-grained, homogeneous and with jointing and bedding not very evident.

The junction between the Biana and the next succeeding stage, the Damdama, is always poorly exposed; towards the top of the Biana stage pebble bands occur and there seems to be a gradation upwards into the thick conglomerates of the Damdama stage, but this may be deceptive and the junction really an unconformity. The break between the Badalgarh and the Damdama stages to the south-east of Sita is very clear. At the entrance to the gorge the Badalgarh stage forms the usual cliff, capped, not by the Biana quartzite as usual, but by the basal bed of the Damdama stage, which lies at an inclination slightly differing from that of the Badalgarh and so truncates the beds of the latter stage one after another. Near the head of the gorge a conglomerate layer comes in at the base of the Damdama stage, rapidly increasing eastwards to a great thickness and below this the Biana stage appears, thin at first. It is uncertain whether the unconformity between the Badalgarh and the Damdama stages is merely local or is continued between the Biana and the Damdama after the former attains its normal thickness.

(d) *Damdama Stage.*

The Damdama is by far the thickest of the stages and increases in thickness more rapidly from west to east than any of the others, owing to a vast accumulation of conglomerates in its lower portion.

Midway along its outcrop it must be about 4,000 ft. thick and is still thicker further to the east. In the conglomerates the following rocks occur as pebbles: white vein quartz, dark quartzite of several hues, jasper rock, vesicular trap, greenish Aravalli indurated shale and phyllite, and quartz-tourmaline pegmatite, all quite unflattened by crushing though often cut through by joints. The topmost beds, forming the dip-slopes south of Lakhanpur ($26^{\circ} 59' : 77^{\circ} 13'$) are dark red and purple, fine-grained, massive quartzite; through them ravines are cut along the dip, exposing the conglomerates and pebble-bands underlying them. Just north of Lakhanpur is a low ridge of thin-bedded, dark quartzitic sandstones and black shales, higher in the succession than the massive quartzites.

(e) *Wer Stage.*

The next and highest stage, the Wer, is separated from the other stages by a distinct unconformity. It is divisible into two portions, the lower of black shales, the upper, and much thicker, of quartzites, but the outcrops of this group are very fragmentary and broken up by spreads of alluvium. The shales are mapped by Hackett as Damdama, although, in his table of formations, he mentions no shales in the Damdama stage, but "black slaty shales" in the Wer. The junction between these shales and the Damdama beds is covered by alluvium, but the strike of the Wer quartzites is closely parallel to that of the shales and both strike for some distance at a considerable angle to Damdama beds. The shales also extend for a long distance further west than the Damdama stage and overlap it, finally resting on the Nithahar beds. It is therefore obvious that the shales should be placed in the Wer stage and that there is an unconformity between it and the Damdama.

From Sita (Silagaon) north-westwards along the strike of the Wer stage, the Nithahar beds are crossed at a low angle to their strike, the end of one bed after another passing in succession below the alluvium in the space separating them from the Wer stage. North of Hathori ($27^{\circ} 0' : 77^{\circ} 10'$) is a thick trap band, less altered than those in the Nithahar stage, with a vesicular crust and succeeded upwards by a quartzitic sandstone. Its base is not seen. It is highly probable that this is a flow poured out on the old land surface at the horizon of the unconformity at the base of the Wer stage. Above this sandstone are the shales, intercalated at their top with

felspathic grits and passing upwards into quartzites; the shales are here 300 to 400 feet thick.

The Wer quartzites are white or pale yellow, hard and free from impurities or from interbedded layers of shale, sometimes vitreous, sometimes granular, massive and almost unbedded and with close and very irregular jointing. They form bold castellated ridges, with their slopes buried in large fallen blocks. To the west, and also near their base, they are more regular in bedding and jointing. The separate fragments commonly weather with a surface covered with small brown dots and pittings, probably where a grain of pyrites has oxidised into the matrix. The thickness of the quartzites is about 2,300 feet at least, but their true upper limit is probably not seen.

LALSOT HILLS.

The Lalsot hills are connected with the exposures of the Alwar series in the type area by two virtually continuous ridges, so that there is no doubt whatever about their correlation with them. A continuous line of outcrop of beds at the base of the series carries on the correlation from Morra in the Lalsot hills to Kondra at the western end of the Biana hills, so that the latter again are linked up through the Lalsot hills with the Alwar beds of the type area. The connecting ranges will be described first.

On each side of the syncline, on the Alwar border, in which the Ajabgarh beds of Mandaor¹ lie, are inward-dipping ridges of Alwar rocks, the more westerly of which has at its base Aravalli granite. They run south across the Banganga river, approaching each other and steepening in dip to verticality and, with trifling breaks, pass into the Lalsot range. From where they join it another narrow line of quartzites, dipping at 70° or more to the south-east, runs north-east to meet the Alipur ridge² in which both Alwar and Ajabgarh beds are present (section B B). North of Toda Bhim (26° 55': 76° 52') the anticline *cd* has narrowed by the pitching of the axis of the fold, while to the south-east (at Toda Bhim) commences another parallel anticline, bounded by inward-facing Alwar scarps and occupied by Aravalli beds (p. 185) almost completely concealed by alluvium.

Section CC shows the beginning of this anticline (*jk*) *a* being the reappearance of the Aravalli granite below the Gisgarh scarp

¹ *Mem., Geol. Surv. Ind., XLV, p. 76.*

² *Mem., Geol. Surv. Ind., XLV, p. 84.*

and *h* where the metamorphics at Morra continue the unconformity of the Biana hills. A little distance to the south-west of the line of this section the minor flexure *cd* dies out and *be* becomes a simple syncline. At Gisgarh the basal beds are red quartz-mica schists with felspathic layers, and compressed arkose grits, derived from the disintegration of the underlying granite; locally, a layer of fine black conglomerate, with quartz and felspar pebbles, lies on the granite. Above these are banded and well stratified pebble-conglomerates, the pebbles chiefly of quartz and smaller than walnuts. There is nothing here analogous to the great accumulations of coarse conglomerates seen at points on the unconformity in Alwar. Following upwards in the section is a cliff of reddish and dark grey, compact quartzite. The two detached hills north of Gisgarh, in both of which the unconformity is displayed seem to have been faulted to the north-west. In one of these, and also 2 miles to the south of Gisgarh, are seen banded epidotic and calcareous slates, which greatly resemble altered tuffs and are probably connected with trap veins in the underlying granite; in the whole of the Lalsot hills these are the only representatives of the basic intrusives so frequently met with in Alwar.¹

The general facies of the rocks here and on the other flank of this anticline, *ab*, is much more argillaceous than the typical Alwar beds. The quartzites are darker and more ferruginous and numerous slate bands occur not far from the base; the purer quartzites are very vitreous, but the slates are not at all schistose. A narrow synclinal valley, *be*, separates, this from the main or central anticline, *jk* (section CC).

The ridge joining the Biana and Lalsot hills Hacket believed to be composed of the Wer stage, the Nithahar having died out and the Wer overlapping it on to the Aravalli beds. I am convinced that he was mistaken in this, for I can find no evidence to support it and the dark grey and purple quartzites with argillaceous bands are much more similar to the dark-hued and heterogeneous Nithahar beds than to the pale-coloured and purely siliceous Wer quartzites. The explanation is probably that, through steepening in dip, the outcrops of the beds of both stages have diminished in width and that the Wer stage is absent, by denudation, from the connecting ridge, but reappears in the plateau north of Morra, where, however, the higher inclination of the strata and absence of good sections

¹ *Mem., Geol. Surv. Ind.*, XLV, pp. 38, 90.

prevent separation of the stages. It is possible, too, that with distance from the presumed original margin of deposition of the stages, accumulation may have been continuous and the unconformity has disappeared; if present, it is certainly not shown by a conglomerate, by lava-flows, or by any marked disparity in the dip or strike of the strata.

Along the base of the ridge the pre-Delhi unconformity is concealed but a thick band of rock occurs, lithologically similar to the Aravalli types seen at Kondra, and is probably the result of their disintegration. A thin quartzite intervenes between this and other similar beds, in places a fairly pure hardened pipe-clay, slightly mottled with pale purple and pink, which is used in the adjacent villages as a whitewash. The ridge is perfectly straight and vertically bedded as far as Morra. West of Morra, a couple of sharp parallel folds bring the unconformity above the surface of the alluvium; and arkose gritty beds, with conglomeratic and slaty layers, are seen to intervene between the above-mentioned argillaceous beds and the Aravalli outcrops. It is more than probable that the steatite deposits of Morra and Dhawain (near Kamalpur), which are on the continuation of the former, have been formed by the concentration of the talcose schists below, just as the white clay band has been formed from the soft Aravalli rocks of Kondra.

Passing from Kamalpur towards the central anticline the edges of the basement beds are crossed obliquely where they run below the alluvium, and they are not seen again on this side of the central valley until they re-emerge near Lauali ($26^{\circ} 34' : 76^{\circ} 33'$) at the other end of the hills; between these places the south-eastern margin of the central longitudinal valley there is a straight and narrow ridge of rocks near the base of the series but on the other flank of the syncline *fg*. Between this ridge, the beds of which dip to south-east, and the north-west or north-north-west-dipping strata of the Morra plateau is a synclinal, or rather isoclinal, valley, *fg* (section CC) in the centre of which near Berod ($26^{\circ} 51' : 76^{\circ} 49'$), is a small hill of black slates which may belong to the Ajabgarh series.

At the end of the central anticline near Toda Bhim, the beds of the Alwar series form a steep-sided plateau (*māla*) in which the dips are nearly vertical, but indistinct owing to the compression which the rocks have undergone. They are fairly white quartzites, but many of the beds weather in a curious cellular fashion, with irregular

or lenticular cavities formed by the removal of ferruginously cemented material, often leaving a quartz sponge.

As far to the south-west as Pail ($26^{\circ} 45' : 76^{\circ} 40'$) the anticline is a simple one bounded by two narrow ranges, that on the north-western side consisting of massive dark quartzites, with paler bands, showing bedding well and dipping outwards at 60° — 75° , the other of reddish, thin-bedded, porcellanic quartzites and dark massive quartzites with black slates above, *i.e.*, towards the south-east. The latter beds are inverted, dipping in the same direction and at the same angles as the opposite ridge. This is analogous to the westward- or north-westward-dipping isoclines which are so common in the Delhi system elsewhere.

Aravalli granite is exposed at only two places within the bounding ranges (p. 186).

At Pail the structure becomes somewhat complicated. The valley narrows to a mere passage between the hills, in which quartzite is exposed, thus isolating the (hidden) expanse of Aravalli beds in the north-eastern or Gudho section of the valley from those in the south-western portion. At the same point the narrow south-eastern ridge abruptly expands into a triangular plateau on which conglomerates are seen, and rapidly contracts again to a line of outcrops as straight as, and even narrower than, before. The north-western ridge bends sharply through a right angle and then again back to its original direction, becoming simultaneously an elongated and level-topped table-land four or five miles wide. At Pail, and for two miles to the north, the outcrops of the beds stop along an almost straight line, presenting their ends to the valley, with long ravines running up from it along their strike. It is probable that here and at the other sudden change of direction there are "tear-faults," or lateral fractures of the strata at the point of flexure, these accounting for the termination of the outcrops (which takes place at both ends of the section where the beds strike north-west—south-east) along straight lines perpendicular to their strike. At Pail a considerable thickness of arkose grits and conglomerates appears in the section, but these die out or pass into normal quartzites a short distance along the strike.

It is evident from the very marked disparity in the thickness of strata exposed on either side of the south-western portion of the valley, in which is situated Moran (Garh on the map, $26^{\circ} 43' : 76^{\circ} 36'$), that the anticline is not now a simple one in continuation of that just

described, between Toda Bhim and Pail. The following explanation is a reasonable one and fully borne out by the field evidence. The axis of the north-eastern, or Gudho, anticline, instead of being continued straight on through the south-western, or Moran, portion of the valley, swings to north-west near Pail and passes along the plateau towards Karomar ($26^{\circ} 39' : 76^{\circ} 30'$), at the same time pitching downwards so that the underlying Aravalli beds no longer appear along the crest but are concealed under the Alwar series. Near Karomar the axis rises again and the Aravalli system though covered by alluvium, is inferred to be free from the superincumbent Alwar series, for the beds appearing in the inward-facing scarps are characteristic of the base of the series. The Moran (Garh) valley is, however, clearly an anticline, the axis of which has pitched high enough to bring the easily denuded Aravalli beds to the surface, but it is not a direct continuation of the Gudho anticline. The plateau bounding the Moran valley on the north-west is there made up of an anticline and a syncline of Alwar beds, the anticline being a continuation of that of Gudho, but it does not give rise to a valley until the axis pitches high enough to carry up the Aravalli rocks, and the syncline intervenes between it and the Moran anticline. The latter is a new fold, *lm* (section EE), which has come in, with its parallel syncline lying to its north-west, between the anticline, *jk*, and the syncline, *fg* (sections DD and EE). In other words, although the Gudho and Moran valleys are topographically continuous, they are not so geologically, for the Gudho valley is structurally succeeded on the line of the same anticline by a plateau and then by a valley, while the Moran valley, its geographical continuation, is on another and parallel anticline. The axis of the Gudho-Karomar anticline, *jk*, probably passes through Jaharo, 1 mile to the north of Pail, and the conglomerates of Pail are some distance above the base of the Alwar series.

The south-eastern boundary ridge of the Moran valley is largely composed of fine-grained, red, yellow and white, splintery, porcellanites and slaty quartzites; along the top runs a band, about 20 yards wide, of white and rather impure kaolin inter-banded with quartzite. Towards Lauali the ridge broadens greatly from the emergence of a considerable thickness of beds which have been concealed beneath alluvium and are the continuation of those about Kamalpur (p. 185). The actual base of the Alwar series at Lauali is not seen. The lowest beds exposed are schists and schistose conglomerates,

some of the latter being fairly coarse, the pebbles of which are mainly of vein quartz and quartzite, with some of black chert. To the north of Lauali the ends of higher beds are crossed, but the basal conglomerates run from Lauali south by west to the end of the syncline, *mh* (sections EE and FF), at Binoli.

The aspect of the plateau on the north-western flank of the valley is the normal one of these *málas*,—almost level, with strike gullies and ridges caused by the differences in resistance of the beds, and covered with sub-angular boulders and a sandy soil supporting thin grass and bushes of “dhao” (*Anogeissus pendula* and *latifolia*), with small “dhak” (*Butea frondosa*) trees in the hollows. Being uncultivated, these elevated tracts are resorted to by communities of herdsmen of the Gujar caste, with their flocks, during the dry season, when pasturage on the plains is insufficient; there the Gujars remain until the water stored in shallow tanks is exhausted, when they descend to the lowlands. I have elsewhere¹ ascribed the striking levelness and equality in height, of these tracts to their being remnants of a former base level of denudation probably of Jurassic times.

The rocks are alternations of coarse and fine, ferruginous, dark and mottled quartzites. Along the axis of the Gudho-Karomar anticline, are soft brown quartzites, by the erosion of which a shallow valley has been formed on the plateau, in which are the permanent villages of Dhowa and Sir. All the rocks are much altered (stratification being often quite obscured), the finer quartzites being vitreous and excessively jointed and quartz-veins are common. As throughout the Lalsot-Biana hills, there are, however, no signs of the intrusive amphibolites, granites and pegmatites characterising the Alwar series in other areas.

In the Karomar valley no granite or Aravalli schists are exposed; but at Gol, opposite Karomar, there are in the Alwar series arkose grits and conglomerates, indicating the proximity of the basal unconformity; and at Lalsot, below a ridge undoubtedly continuous with that of Gol, the junction is admirably shown. The form of the valley and the dips of the beds on either side support the idea that it is eroded along a tongue of Aravalli rocks extending into the hills along an anticline.

At Lalsot the basement bed of the Alwar series is a compact black vertical quartzite, with a line of pebbles of pegmatite and of

¹ *Mem., Geol. Surv. Ind.*, XLV, p. 32.

vein-quartz at the contact. Grits occur but are not at all in force; this section again shows that a violent unconformity may occur without the formation of conglomerates. The black colour of the basement bed, like that at Gisgarh (p. 194), suggests the carbonaceous soil of an old land surface.

MINERALS OF ECONOMIC VALUE.

Copper.

A mile west of Nithahar is a small copper working in the Nithahar beds; it is a narrow and inclined open-cut. Nithahar. No trace of a vein was visible and practically no ore was to be seen strewn about.

Another disused copper mine is said to be situated to the south or south-west of Hathori, but I could neither find the mine nor anyone who knew its location. Hathori.

$\frac{1}{2}$ -mile north of Lalsot in the Alwar quartzites a shallow open cutting has been sunk for a few feet along the hill and some of the débris lying about shows films of green copper carbonate. Lalsot.

In the Rupali (map: Rupalee) hill, $\frac{1}{2}$ -mile south-east of Moran (Garh), there are several small pits at the north-eastern end of the hill, but I could find no trace of any copper ore, nor of the shaft, 20—30 feet deep, mentioned by Hackett.¹ Moran.

Iron.

Iron has been worked in the distant past near Jhaj, 2 miles to the south of Hathori ($27^{\circ} 0' : 77^{\circ} 10'$), in a great trench. The ore was probably a breccia cemented by hematite, as seen in the grits adjoining. It is too impure to be of any value at the present day. Jhaj.

On the top of the plateau above Toda Bhim, near Mandnaoj, a small quantity of a substance called *kachéra* is worked by an Agra contractor, who is said to use it, presumably pulverised, to give weight and colour to lac bangles. It consists of small nodules and plates of reniform Mandnaoj.

¹ *Rec., Geol. Surv. Ind.*, XII, p. 247.

hematite (perhaps manganiferous), formed as concretions and infillings in the joints of the quartzites, and weathered out into the thin soil covering the rock.

Steatite (*ghia bhāta*).

The steatite quarry is in the scarp of Alwar beds immediately west of the town. It opens up a very small mineral body and has not been worked for fifteen years, as the pieces got out became too small for the manufacture of toys and plates. The steatite could only be followed for a short distance along its strike, the rest being covered with scree from the quartzites above; its greatest thickness is 2 feet. It behaves like a sill, splitting into two and running along the strike of the quartzites, which here have in them bands of schist and limestone. Its colour is rather dark green and it is much more impure and in much less amount than the occurrences of Morra-Bhandari (*infra*) and Dogetha in Jaipur.¹

$\frac{1}{4}$ -mile to the west of Kawa (1 mile west-south-west of Moroli, 26° 46' : 76° 34') a considerable amount of steatite was dug out of a deep well sunk at the foot of the dip-slope of Alwar quartzite; it is nowhere exposed at the surface.

These are the deposits referred to by Hackett² as the source of the stone used by the Agra stone-carvers. They extend for about 5 miles near the base of the Alwar scarp between Dhota (26° 48' : 76° 48') and Morra (26° 49' : 76° 52'). The workings are in the richer pockets of a stratum of talcose schist, which I have suggested (p. 185) may be derived from the underlying Aravalli rocks by concentration on re-deposition. The first excavation is immediately to the west of Dhota, in a bed about 25 feet thick. The steatite is harder than that of Dogetha in Jaipur, and has in it thin films of calcite, but hardly any pink iron staining. There seems to be present a little kaolin and perhaps disseminated quartz. In colour it is white or pale green. It has a vague foliation along the strike, but no jointing is apparent. This mine is now closed; formerly its output is said to have gone to the Punjab. Between Dhota and Morra are five or six places where the same bed has been opened up

¹ *Mem., Geol. Surv. Ind.*, XLV, p. 125.

² *Rec., Geol. Surv. Ind.*, XIII, p. 250.

but a locality at 1 mile to the west of Morra is the only place at which any work is being done. The contractor, Johari Lal of Agra, was said to pay a rental of Rs. 830 per annum to the Jaipur State and to export about 20,000 maunds annually; royalty works out therefore at $\frac{2}{3}$ annas per maund; excavation and loading on carts costs $1\frac{1}{2}$ annas per maund and cartage to Hindaun City Station 3 annas. The total cost, to the railway, is therefore $5\frac{1}{6}$ annas per maund or Rs. 9 per ton. My figures were obtained from the workmen and may not perhaps be accurate. The contractor endeavours to get large blocks, and compact, rather hard stone of a greenish colour is most appreciated. As it is inconceivable that the demand for the familiar models of the Taj and other Agra curiosities can account for 20,000 maunds per annum, Agra must, if my figures are correct, be a distributing place for its use in other industries such as soap-making, rice-polishing, and sizing and weighting cloth. The Morra mine is an adit going a long distance into the hill, and branching into two at about half-way in. No information as to the shape of the deposit or its relation to the other rocks could be obtained. The hard cellular masses of iron-stained quartz or calcite are not nearly so common as at Dogetha; they are quite irregular both in shape and distribution.

Kaolin and pipe-clay (*khari*).

At $1\frac{1}{4}$ miles to the south-east of Rasnu ($26^{\circ} 41' : 76^{\circ} 37'$), a long and spacious tunnel has been driven along the strike of a bed of kaolin, which runs midway in the ridge of Alwar quartzites. It is about 60 feet thick, white but rather impure, and banded with quartzite. There is a very large quantity available, but it has been quarried for local purposes only, such as white-washing.

Kaolin is also dug from the soft argillaceous and talcose zone near the base of the Alwar series in the ridge joining the Biana and Lalsot hills, chiefly near Mathasur ($26^{\circ} 55' : 76^{\circ} 59'$). There are two beds, separated by quartzite, the upper yielding a white and fairly pure clay, slightly mottled with pale purple and pink.

Thermal Springs.

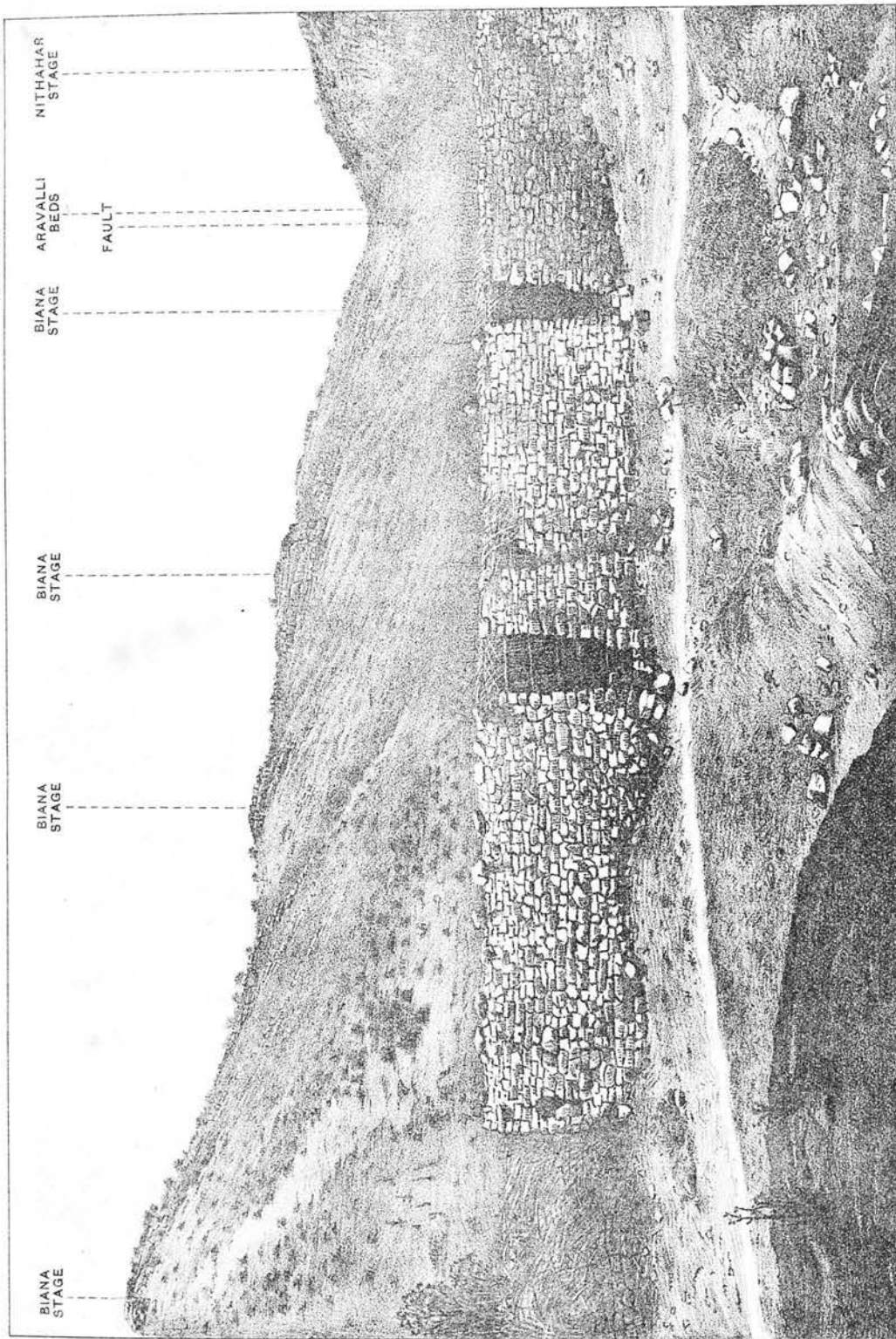
There are several sources of hot water in the Lalsot hills, none of them gaseous or mineralised. That at Moran (Garh) is well-known

and perennial; it is tapped and flows into a masonry tank. Near Gunah ($26^{\circ} 47' : 76^{\circ} 41'$) is a well the water of which is slightly warm, as is also the case in several of the wells below the hill at Toda-Bhim, while those a short distance away on the plain are at the normal temperature; the former probably draw their supplies from rock springs and the latter from the ordinary sub-soil circulation. At Jaharo ($26^{\circ} 46' : 76^{\circ} 40'$) is a *kund*, or masonry tank, the water in which is appreciably cold.

INDEX OF LOCALITIES.

| | Latitude. | Longitude. |
|---------------------|------------------|------------------|
| Badalgarh | $26^{\circ} 53'$ | $77^{\circ} 18'$ |
| Bagren | $26^{\circ} 55'$ | $77^{\circ} 13'$ |
| Barhika | $26^{\circ} 55'$ | $77^{\circ} 14'$ |
| Berod | $26^{\circ} 51'$ | $76^{\circ} 49'$ |
| Biana | $26^{\circ} 55'$ | $77^{\circ} 21'$ |
| Damdama | $26^{\circ} 55'$ | $77^{\circ} 20'$ |
| Dhota | $26^{\circ} 48'$ | $76^{\circ} 48'$ |
| Gisgarh | $26^{\circ} 53'$ | $76^{\circ} 42'$ |
| Gudho | $26^{\circ} 47'$ | $76^{\circ} 43'$ |
| Gobindpur | $26^{\circ} 57'$ | $77^{\circ} 10'$ |
| Gunah | $26^{\circ} 47'$ | $76^{\circ} 41'$ |
| Hathori | $27^{\circ} 0'$ | $77^{\circ} 10'$ |
| Jaharo | $26^{\circ} 46'$ | $76^{\circ} 40'$ |
| Jhaj | $26^{\circ} 58'$ | $77^{\circ} 11'$ |
| Kamalpur | $26^{\circ} 48'$ | $76^{\circ} 49'$ |
| Karawli | $26^{\circ} 57'$ | $77^{\circ} 9'$ |
| Karomar | $26^{\circ} 39'$ | $76^{\circ} 30'$ |
| Kondra | $26^{\circ} 57'$ | $77^{\circ} 2'$ |
| Lakhanpur | $26^{\circ} 59'$ | $77^{\circ} 13'$ |

| | Latitude. | Longitude. |
|---------------------------|-----------|------------|
| Lalsir | 26° 45' | 76° 39' |
| Lalsot | 26° 34' | 76° 23' |
| Lauali | 26° 34' | 76° 33' |
| Mathasur | 26° 55' | 76° 59' |
| Moran (Garh) | 26° 43' | 76° 36' |
| Moroli | 26° 46' | 76° 34' |
| Morra | 26° 49' | 76° 52' |
| Nithahar | 26° 58' | 77° 6' |
| Pahari | 26° 47' | 76° 56' |
| Pail | 26° 45' | 76° 40' |
| Rasnu | 26° 41' | 76° 37' |
| Sita (Silagaon) | 26° 59' | 77° 11' |
| Talchiri | 26° 54' | 77° 5' |
| Toda Bhim | 26° 55' | 76° 52' |
| (Wer Wair) | 27° 1' | 77° 14' |



From a photograph by A. M. Heron

ARAVALLI SYSTEM, NITHAHAR, BADALGARH AND BIANA STAGES.

Barhika near Bagren (looking north-west.)

Litho G. S. I. Calcutta.

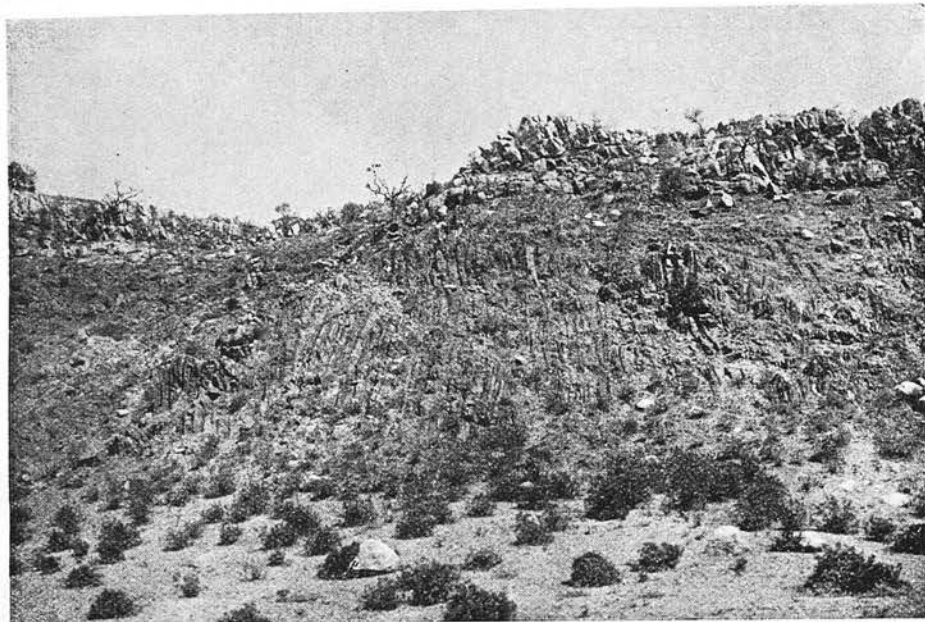
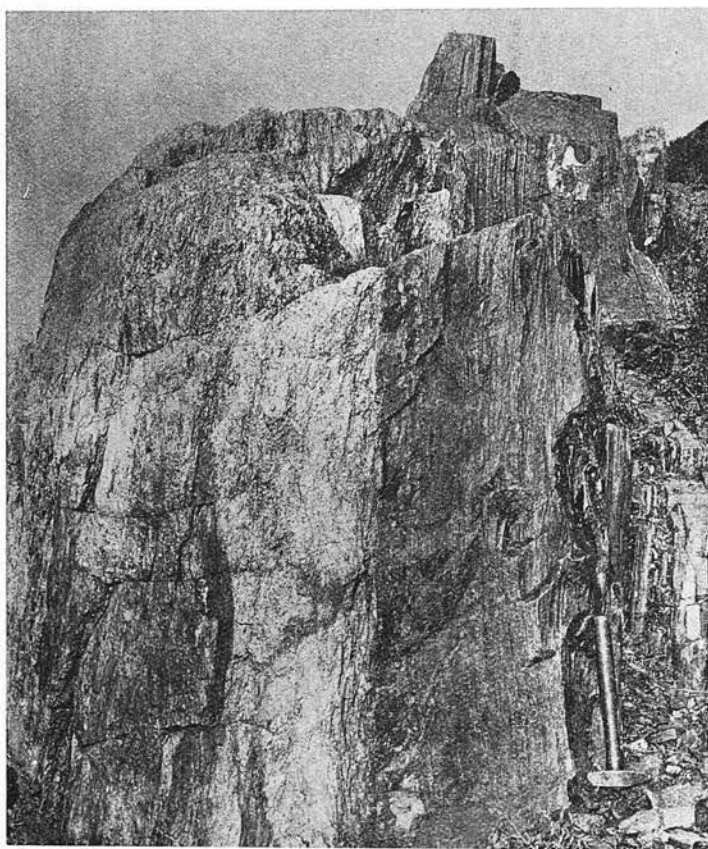


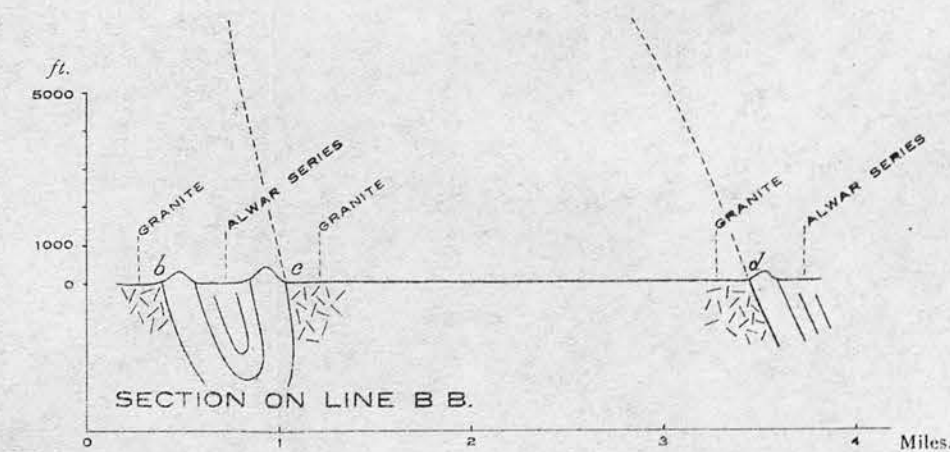
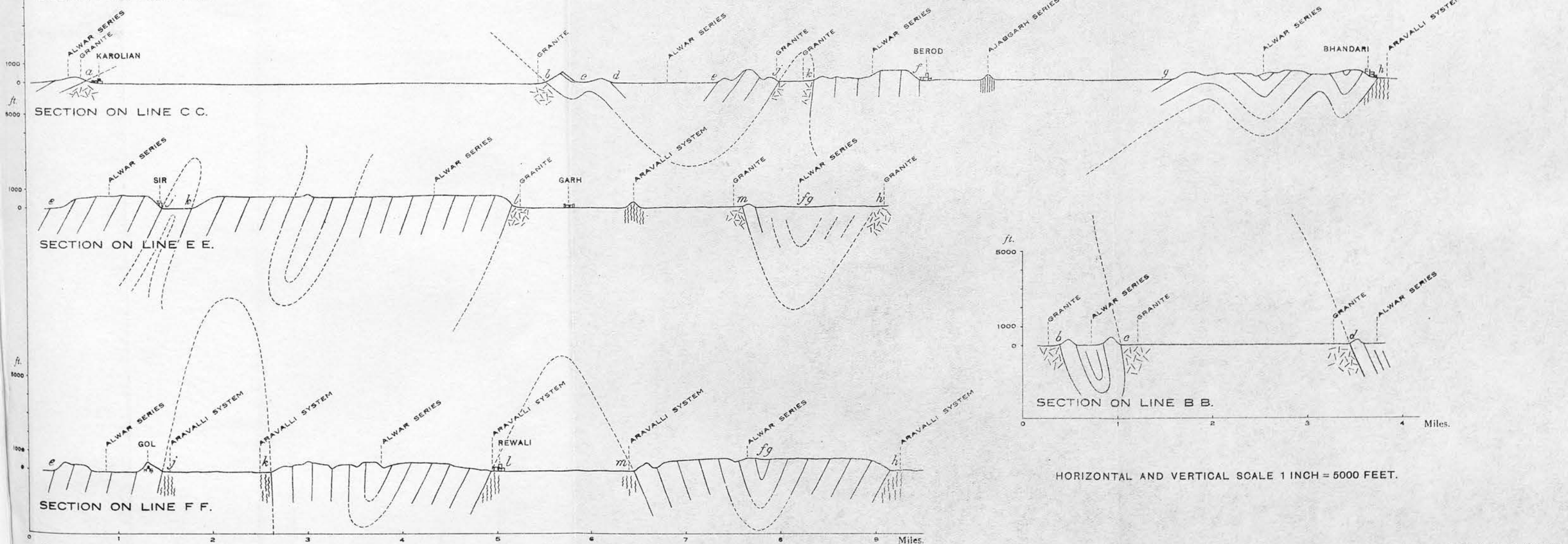
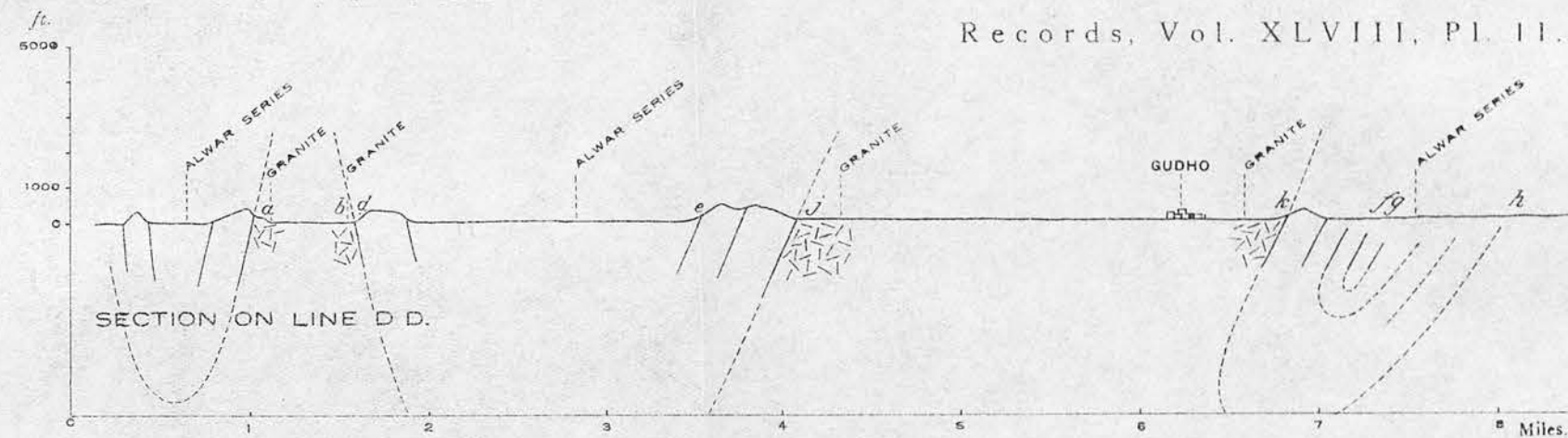
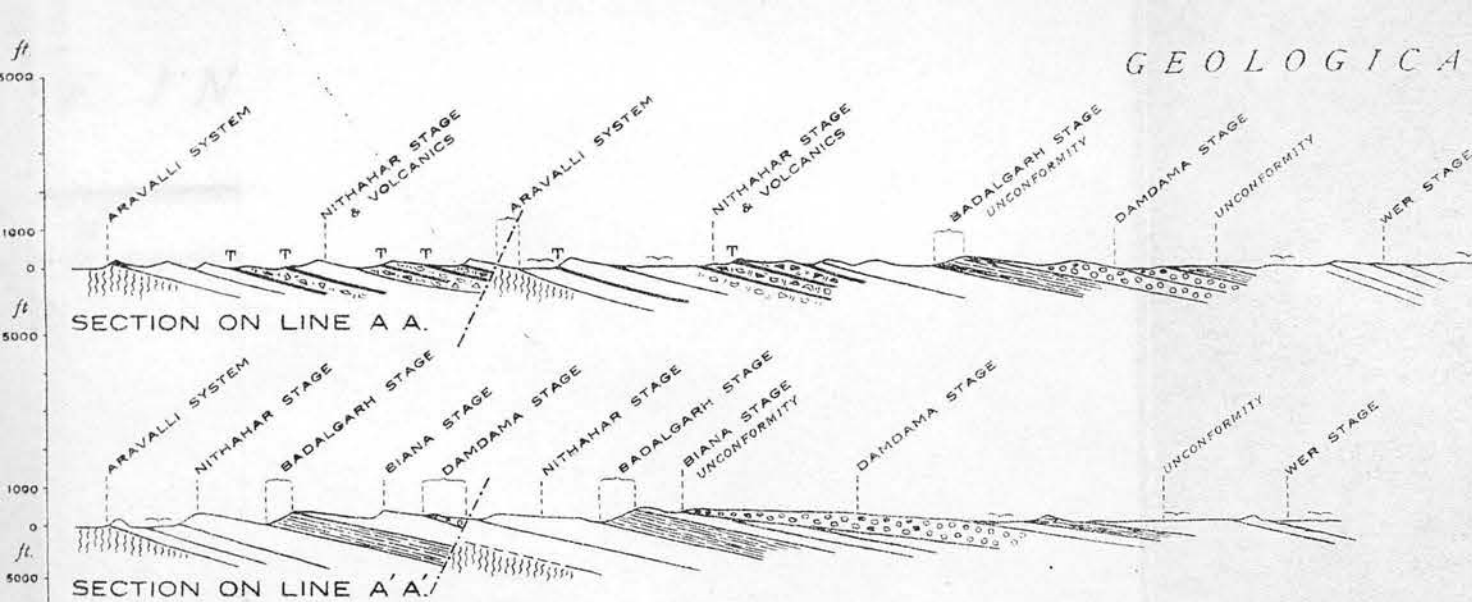
FIG. 1. NITHAHAR QUARTZITE UNCONFORMABLE ON ARAVALLIS
NITHAHAR (Looking North.)



Photographs by A. M. Heron.

G. S. I. Calcutta

FIG. 2. VERTICAL ALWAR QUARTZITES, (right,) UNCONFORMABLE ON ARAVALLI SCHISTS, (left.)
LALSOT (Looking North-West.)

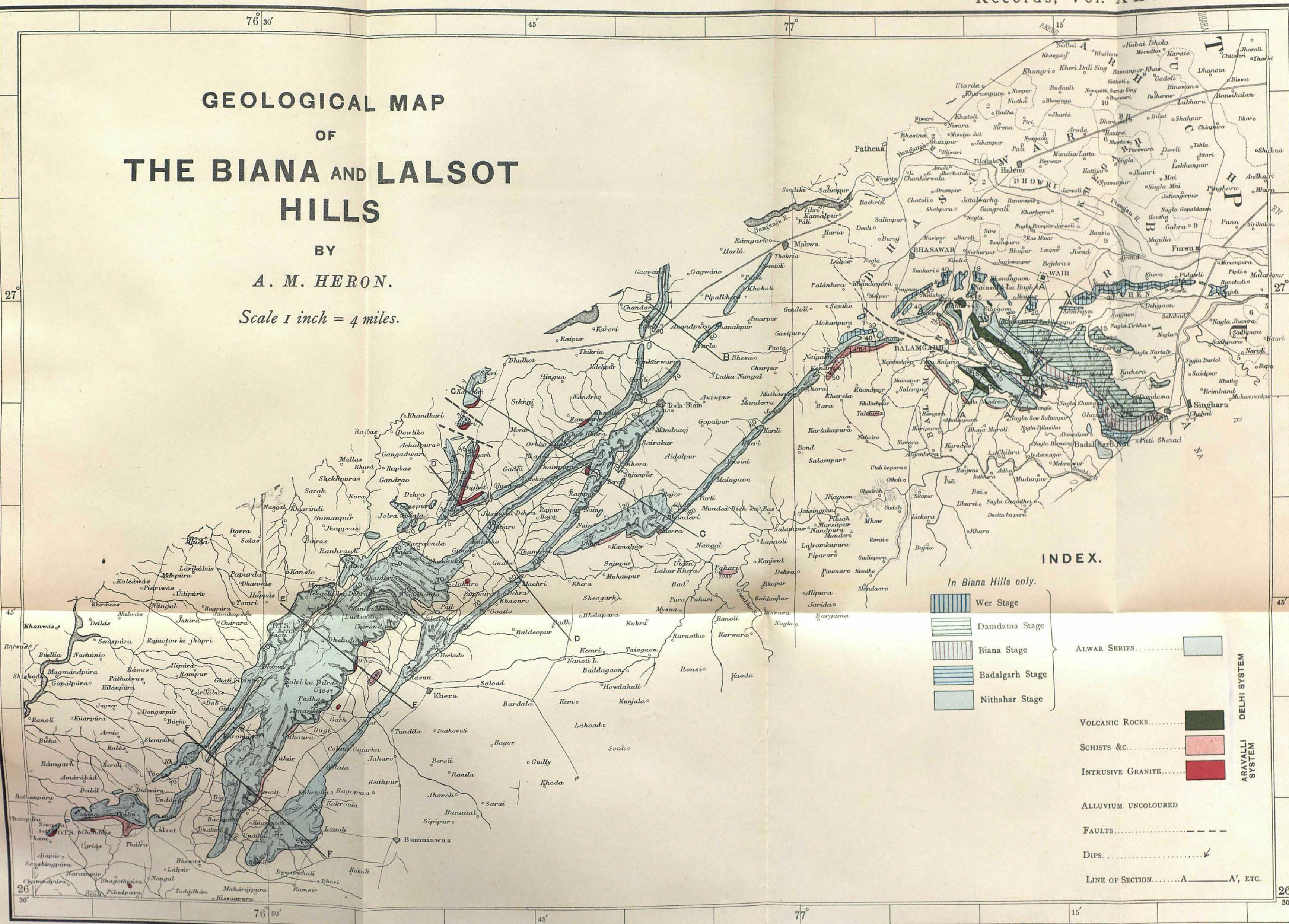


HORIZONTAL AND VERTICAL SCALE 1 INCH = 5000 FEET.

GEOLOGICAL MAP OF THE BIANA AND LALSOT HILLS

BY
A. M. HERON.

Scale 1 inch = 4 miles.



This is submitted for the degree of D.Sc.

MEMOIRS

OF

THE GEOLOGICAL SURVEY OF INDIA

VOLUME XLV, PART 1.

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ASSOC. INST. C.E., *Assistant Superintendent, Geological
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With Professor Hudson Beare's Compliments

Mr Heron's thesis for the D. Sc.

Other copy sent to Dr Horne.

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CHAPTER I.

INTRODUCTION.

The general resurvey of Rajputana, of which the present memoir describes a portion, was commenced in 1908, and was undertaken largely because of the uncertainty regarding the true succession of the rocks of this region and of the validity of separating off a portion of the strata to form the Delhi System or Series. Though previously surveyed by Mr. C. A. Hacket in the seventies of last century, his published papers were too brief to give an adequate idea of this large and complicated area, and considerable confusion had arisen by his change of view about the position of the Ajabgarh and Raialo series. Although I am obliged to differ greatly from his revised opinions of the succession, my conclusions are practically in agreement with those laid down in his first paper, an excellent synopsis of the geology of the area so far as the non-igneous rocks are concerned, and I am fully aware of the advantages I have enjoyed in having his work to build upon. I have in addition had the powerful assistance of the petrographical microscope in working out the structure of the rocks, a means of research but little employed in his time, and I have been enabled to apply to the area the results of the great advances since

his day in our knowledge of the crystalline and metamorphic rocks of India and elsewhere.

My criticism of his views must not be considered inconsistent with a strong feeling of indebtedness to him as the pioneer worker.

I was able to consult his detailed maps, but nowhere took anything for granted, and carried out my resurvey Mapping. in detail and entirely *de novo*. In cases where I found my mapping at variance with his I, of course, took extra precautions to ascertain the truth.

Mapping was done on the standard sheets of the topographical survey, scale one inch to the mile; the map on the quarter-inch scale, which accompanies this memoir, is reduced from these with no more generalisation than is required by reason of the reduced scale.

The area described in the ensuing pages, about 9,000 square miles, comprises the solid geology of Raj- Extent of area. putana east of longitude $76^{\circ} 10'$ and north of latitude 27° , roughly a triangle the vertices of which are the cities of Agra, Jaipur and Delhi.

Politically it lies largely in Rajputana, comprising the whole of the State of Alwar, about three-quarters of Bharatpur State, the whole of the Nimrana Chiefship, and strips of Jaipur State to the south-west. Outside Rajputana it includes in the Punjab much of the Gurgaon District, part of the Delhi District and small portions of detached parganas of Nabha and Patiala States, and, in the United Provinces, a small part of Muttra District. Political divisions.

The work occupied most of the field-seasons 1908-09, 1909-10, and 1910-11, as part of the programme of the Central India and Rajputana party, under the superintendence of Mr. C. S. Middlemiss, to whom I am greatly indebted for much assistance and advice.

PREVIOUS OBSERVERS.

1824, J. B. Fraser.—“Description of journey from Delhi to Bombay,” Transactions of the Geological Society.

An accurate account of the rocks passed over on the journey. The line of march, however, lay through the plain to the east of the Alwar hills, and missed most of the solid geology of this area. He

was apparently struck with the level summits of the hills near Alwar :—

“One of the remarkable characteristics of this portion of the range, its regularity of height, is conspicuous on looking down upon it from the superior height of Alwar fort, from whence all the hills appear to rise nearly to a level, stretching out with this uniform appearance far to the west and north-west, and in fact quite bounding the view in these quarters.”

1830, “*Geology of Bhartpur*.”—Gleanings of Science, II, p. 143.

Mainly descriptive of the Upper Bhander plateau and the sandstone quarries, and merely mentions the ridges of quartzite to the west and north-west of Bharatpur City.

1867, *C. Campbell*.—“Rewaree Slate Quarries,” Professional papers on Indian Engineering, 1867.

This is accompanied by a fairly accurate geological sketch-map of the vicinity of Rewari, in which however the Alwar quartzites are mapped as gneiss. He describes slate exposures at Pali, Manahti (Manetee), a sacred hill 3 miles east of Rewari, and at Papree near Pentungwa (Pinangwan, p. 79), and regards those at Manahti as the only useful ones, *i.e.*, the quarries at Kund Ry. Stn. now worked by the Kangra Valley Slate Coy.

1877, *C. A. Hacket*.—“Note on the Arvali Series in North-Eastern Rajputana,” Rec. Geol. Surv. India, X, pt. 2.

The most important account of the area, in which is given the classification of the strata which I have followed as far as possible. The igneous intrusives are however not separated from the sedimentary rocks, and the paper is unduly short to describe such a large and varied region.

1878, *Major P. W. Powlett*.—“Gazetteer of Ulwar.”

A most interesting and exhaustive account of the Alwar State, containing much information about its topography and economic geology, with an appendix by Mr. C. A. Hacket which is practically identical with the last mentioned paper.

1879, *H. B. Medicott*.—“Annual Report of the Geological Survey of India for 1878,” Rec., Geol. Surv. India, XII, pt. 1.

In this the reasons for Hacket's change of view with regard to the position of the Ajabgarhs are given, particular attention being drawn to the mixed and variable character of the Raialo group and its similarity to the Ajabgarhs. Evidently the Raialos have been

confused with the schists below the unconformity, for the Raialos I have found in reality to be most constant (*i.e.*, the limestone) and utterly different in every way from the Ajabgarhs and the pre-Delhi schists.

It is admitted by Mr. Medlicott that the groups thus arranged present almost incompatible variations to each other and to the gneiss, and various inadequate suggestions are advanced to explain these. The discrepancies will be found to vanish when the true succession of the divisions as herein developed is adopted and when it is realised that there are two "gneisses," one a pre-Delhi granite and the other intrusive in the Delhis. (See Chapters III and IX.)

1879, *H. B. Medlicott, W. Blanford and A. O. Hume*.—"Rajputana Gazetteer."

In this the metamorphic rocks are merely mentioned—"a very complicated series, made up of strong quartzites, slates and limestones, schists with much hornblende rock, and pseudo-gneiss."

1880, *C. A. Hacket*.—"Useful Minerals of the Arvali Region," *Rec., Geol. Surv. India*, XIII, pt. 4.

A comprehensive list and description of all the known mineral occurrences of the region. (See Chapter XII.)

1881, *C. A. Hacket*.—"On the Geology of the Arvali Region, Central and Eastern," *Rec., Geol. Surv. India*, XIV, pt. 4.

This paper is concerned with a much wider area than Hacket's 1877 paper and embodies the changes in the classification which my resurvey has obliged me to reverse.

1882, *T. Oldham*.—"Thermal Springs of India," *Mem., Geol. Surv. India*, XIX, pt. 2, pp. 33—35.

There are several warm springs issuing from the foot of the hills, of no great interest or quantity of water except in the case of Sohna and Naraini. I have little to add to the particulars given by Oldham, from whose memoir I extract the following accounts.

"136, Sunah (Sohna), $28^{\circ} 13'$, $77^{\circ} 6'$, elevation about 800', temperature 108° . The spring is about 33 miles south of Delhi and about 15 from Gurgaon, on the eastern face of, and close under, the Murat (Mewat) hills, near to one of the most craggy and precipitous parts of the ridge.

Water gives off a strong smell of sulphur; sulphuretted hydrogen is thrown out; no iron.

The well or basin into which it rises has been cut out of the solid rock, 16 feet square and about 30 feet deep covered by a dome

and surrounded by apartments, with an open verandah, which are now occupied by Brahmins, said to have been constructed by a Brinjara. *Ludlow* (1826), *Trans. Med. Phys. Soc.*, Calcutta, III, 19. See also *Baird Smith*, *Jour. Asiat. Soc.*, Bengal, XII, 270.

Jacquemont, *Jour.*, III, 337.

The spring is said to have run cold after the earthquake of the 19th February 1842. The temperature is 125° according to *C. E. Smith*, *M.D.* *Official Returns*. This spring is also noticed in the *Ain-i-Akbari*. Gladwin's Translation says: Near the town of Sehnah is a spring of hot water upon a mountain; this certainly is occasioned by a mine of brimstone. *Ayees Akbary*, Vol. III, page 89. Given by *Buist* (*Trans. Bom. Geog. Soc.*, X, 1852) as two springs under the two distinct names of Sonah and Soneeb, Delhi.

137, Pakul. Lat. $28^{\circ} 21'$, Long. $77^{\circ} 17'$.

This is noticed in the *Ain-i-Akbari* as Islamabad, which, Mr. Blochman informs me, is another name for Pakul, near Pali, to the South of Delhi. I know nothing more of this spring than this notice. It is said that "on the mountains of Islamabad is a very deep spring of hot water; it is called Purbhuss, and is a great place of Hindu worship." Gladwin's Translation, Vol. III, page 89. The true reading is *Prabhas kund* i.e., pilgrimage well.

140, Talbrik (Talbrich) Lat. $27^{\circ} 30'$; Long. $76^{\circ} 25'$; Temp. 118° .

This is about $14\frac{1}{2}$ miles from the city of Alwar to the west by south, and about 5 miles from Narainpura to the east. Temperature unpleasantly warm, *C. A. Hackett*, G.S.I.

Water quite clear, Temp. 108° in 1870. *Selections, Government of India*, XC, 78.

This is evidently the hot spring, 15 miles west by south of Alwar, mentioned by *Bellew* and quoted by *Macpherson* (*Indian Annals of Med. Science*, Vol. III, 1854).

141, Koilesar, Lat. $27^{\circ} 4'$, Long. $75^{\circ} 53'$ (correct Long. $76^{\circ} 27'$ A. M. H.).

A hot spring at Koleshar, in the district of Dowsah, *Official Returns*.

Macpherson (*loc. cit.*), quoting *Bellew*, mentions a spring in the Alwar country, "20 miles north-east of Jeypore." I have not been able to identify it; it does not seem to be any of the three noticed above. *Schlagintweit* quotes it in his list (*Jour. As. Soc. Beng.* XXXIII, pp. 49 *et seq.*) as Jaipur, although it is distinctly

stated to be in the Alwar country, and he gives (No. 31 of his list) the latitude, longitude, and elevation of Jaipur town as that of the spring."

This last is probably the locally well-known spring of "Naraini" $2\frac{1}{2}$ miles W.N.W. of Baldeogarh, much revered by the barber caste in particular. It is in the Alwar State, about 35 miles E.N.E. of Jaipur, not 20 miles as Macpherson gives it, but this distance is certainly wrong as no part of Alwar territory lies nearer to Jaipur City than 25 miles. It is tepid and flows into a masonry bathing tank surrounded by the usual temples. The water it discharges is sufficient to irrigate several fields and is not salt nor sulphurous but quite tasteless. Its flow is more copious than any other spring I have seen in Rajputana. That at Talbrich was, when I visited it, a mere trickle, smelling strongly of sulphuretted hydrogen, over black ooze strewn with the ashes of cremated dead, in the midst of a dismal jungle of prickly pear. The springs of Pakul and Koilesar I did not know of when I was in their neighbourhood and heard nothing about them from the people, so they cannot be deemed of much importance. Those of Sohna, Talbrich and Naraini are widely celebrated.

1884, *T. F. Andresen*.—"The Mineral Wealth of Ulwar State" Mining Journal, 1884, p. 1029.

A full description of the Rajgarh and Daribo mines, and methods of smelting and refining copper at Daribo.

1893, *R. D. Oldham*.—"Manual of the Geology of India" pp. 68-71, 103.

1902, *E. W. Vredenburg*.—"Imperial Gazetteer, Provincial series. Rajputana," pp. 6, 52, 425.

PHYSICAL FEATURES.

In this region we have an excellent example of an ancient folded mountain complex reduced to its penultimate stage of denudation. The axis of the chain lies probably to the west, in Torawati and Shekhawati, where the metamorphism of the component rocks is at its maximum and igneous intrusives are much more abundant.

Here it is displayed like a skeleton, in which the softer strata have been largely removed and the harder beds stand out like ribs traversing the alluvial plains.

The general strike is about N.N.E.-S.S.W., with many irregularities; dips are always high, between 60° and 90°, and overfolding is frequent on the western and north-western sides of synclines, where dips are commonly steeper than on their eastern and south-eastern sides, showing that the thrust which folded the strata came from the west and north-west and tended to form isoclines with their axial planes inclined in that direction.

About the plains little need be said except that they slope downwards imperceptibly from about a thousand feet above sea-level around the hills eastwards to an average of six hundred feet near the Jumna.

The streams that meander through them have broad sandy beds which contain water for only a few hours after heavy rain, except where it is artificially retained by embankments.

Practically none of them reach the Jumna, for their drainage is absorbed or floods the low country in Gurgaon and Bharatpur, but they serve to raise the water level in their vicinity, a great boon to the cultivators in view of the extensive use made of well-irrigation.

Only three streams are important enough to have received names. The Sabi, which receives the Sota within our area, and drains its northern part, flows into the Najafgarh jhil, four miles N.W. of Gurgaon town, and ultimately into the Jumna at Delhi through the Najafgarh cut, when the jhil¹ overflows. The Badi or Baraki Nadi or Ruparel carries the rainfall of the central mass of hills near Alwar, partly into the Kotila jhil between Firozpur and Nuh in Gurgaon District, and partly into several large jhils in the extreme north of Bharatpur State. The disposition of its waters has been the subject of a protracted lawsuit between the Alwar and Bharatpur States from early in last century. The Banganga drains the south of the area as well as much of Jaipur, and flows through the south of Bharatpur, reaching the Jumna below Agra by indefinite channels.

The features of relief are due to the out-cropping of the hard beds of the Alwar Series, and to a lesser extent the Ajabgarhs, repeated again and again in closely pressed folds.

¹ "Jhil" is the term (lit. *water*) used in Northern India for an expanse of flooded land, which dries up wholly or partially during the dry season, and often affords excellent duck and snipe shooting in the cold weather.

The valleys are all strike valleys and are of two kinds, (a) the narrow "chhínds" formed by the removal of easily eroded beds interbedded between those more resistant and (b) the broader and longer synclinal valleys excavated in the weak supra-Alwar rocks contained in fold-basins of the Alwars.

This coincidence, abnormal in a folded region of mature topography, of valley with syncline, and the prevalence of striking dipslopes instead of scarps, are the most noteworthy features of the topography. Their causes are the same—the high dips of the rocks, and the homogeneous and resistant character of the Alwar Series as compared with the softer and more heterogeneous, and therefore weaker, supra-Alwar rocks.

Another very striking feature of the scenery is the absence of outstanding peaks among the Alwars and the level line of the summits of the ridges. Looking westwards from the plains near Alwar City towards the main hill-mass, or eastwards to the boundary ridge between Alwar and Gurgaon, or from the centre of the Ajabgarh valley to the containing hills, they appear like a wall rising above the plain and remind one of the Deccan Trap plateau seen from below. On closer examination they resolve themselves into parallel ridges with narrow straight tops. This appearance is strongly commented on by J. B. Fraser, the earliest observer of this region (see p. 3).

The level of the summits is greatest to the west of the Ajabgarh valley,¹ about 1,100 feet above the plain, and falls steadily and gradually to the north and east in the same direction as does the level of the plain but with a steeper gradient, so that they approach each other; thus in the Alwar-Gurgaon boundary ridge the difference between the two is about 400 feet as a rough average, decreasing to 80 feet at the Mutiny Memorial on the Ridge at Delhi.

One cannot but believe, so distinct is the phenomenon, that this is an ancient "base-level of denudation,"
 Old base-level of erosion. upraised and now being redenued to a new and lower base-level.

I advance the suggestion that this old plane of erosion may represent the land surface at the time when the Jurassic and Nummulitic beds of Jaisalmer were being laid down. A similar planing of the tops of hills has been observed by Mr. Middlemiss in Idar State, which he has traced into connection with the floor of the nearly horizontal Ahmednagar sandstone, most probably of Umia

¹ The highest point is 2,542 feet, above Badgaon.

age. Among the hills which do not rise to this hypothetical plane there is no such regularity, the crests being of all heights; though very many of the ridges attain this maximum, none ever exceed it.

The colours of the various formations and their peculiar weathering characteristics in the mass are distinctive, and would make "field-glass geology" a less risky proposition than it usually is.

The Alwar quartzites are pale grey, the grits grey inclining to pink, being more arkose; the quartzites form bold and mural hills, with well developed dip-slopes, the grits weather similarly to granites.

The Kushalgarh limestone is usually in too small exposures to be conspicuous, but forms tracts of low hummocky rock of a deep black hue and an appearance which may best be likened to shagreen on a large scale.

The hornstone breccia, of various shades of brown, gives small steep cones or knobs, rugged or smooth in outline depending on the amount of fragments strewn the slopes.

The slates of the Ajabgarh Series are rusty-black in the mass and give rise to conical peaks and serrate ridges, the Ajabgarh quartzites are usually dark brown and have a curious ribbed and sinuous aspect, described in Chapter VIII.

The granites form the tors and domes which they usually do in dry climates with a considerable daily temperature range, and the amphibolites, though very seldom conspicuous, give smooth, rounded hills of reddish earth covered with subspherical and exfoliating blocks.

CHAPTER II.

GEOLOGICAL FORMATIONS.

TABLE OF FORMATIONS PRESENT.

| | | | | |
|------------------------------------|---|--|--|---|
| Post-Tertiary. | | | | Recent and Sub-Recent — Soil, alluvium, blown sand, and nodular limestone (‘Kankar’). Unconformity |
| | | | | <i>Ajabgarh Series</i> — Slates and phyllites, quartz- itic sandstones and quartz- ites, impure limestones, several thousand feet thick. |
| Delhi System— Purana . . . | Intrusive— Pegmatites and quartz-veins. Granites. Amphibolites. | | | <i>Hornstone breccia</i> — Very variable thickness. <i>Kushalgarh limestone</i> . . . 1,500’ <i>Alwar Series</i> . . . 10,000—13,000’ Quartzites, arkose grits and conglomerates, lime- stones and mica schists, contemporaneous volcanic rocks. <i>Raialo limestone and quartzite</i> . . . 2,000’ Unconformity. |
| Aravalli System— Archaean . . . | Intrusive— Quartz-veins. Granites. Amphibolites. | | | Mica-schists, crystalline limestones, quartzites, and schistose conglomerate. Thickness unknown. |

In the above table of formations I have used Sir Thomas Holland’s scale of the Indian formations as formulated in Vol. I., Chap. II, of the Imperial Gazetteer of India.¹

The oldest rocks consist of granites and very highly metamorphosed quartzites, mica-schists, limestones and conglomerates.

In this area there is no direct evidence as to the relationship of the granites and the metamorphics, but their general arrangement and the fact that in southern Jaipur similar granites are found to be intrusive in similar metamorphics leaves little room for doubt that here also the altered sedimentaries are the older and the granites are intrusive in them.

¹ *Trans., Min. and Geol. Inst. India*, I, p. 48 (1906).

It has not been possible to divide up the metamorphics, so, in the absence of contrary evidence, they may all be included in the one system.

The granites are what Hacket in his earlier paper designated "Gneiss"; on the map accompanying it he has not mapped the metamorphics as distinct from the overlying Alwars, but they correspond with his "Schist Series" indicated elsewhere, near Nitahar.

In the map attached to this memoir I have been unable, owing to its small scale, to colour the granites and the metamorphics separately, but I have described in the text their various occurrences.

Upon these lies the Delhi System, separated from them by a violent and very clearly seen unconformity
Unconformity. which has probably a more or less close approximation to the Great Eparchæan unconformity of North American geologists and that which in India separates the Purana and Archæan groups of Sir Thomas Holland (loc. cit.).

It is perhaps as well to emphasize the fact that this is no mere local break, or a seeming unconformity deduced through a misinterpretation of faulting, intrusion, or crush conglomerates. It can be followed within this area and far beyond it to the east, west and south, wherever its horizon is exposed, for about 200 miles, tracing the most intricate flexures along the margins of synclines of the Delhis folded into the older rocks, and marked by a profound discordance in dip, in strike and in lithological type between the rocks above and below it. Arkose grits and conglomerates are nearly always in force and in places attain a thickness of several hundred feet.

The interval represented by this unconformity was of sufficient duration to allow of the underlying system of rocks to be highly folded and denuded, and great bosses of coarse granite which had been intruded into them to be laid bare.

Above it is the Raialo limestone and quartzite or, where they are absent, the basal beds of the Alwar Series.
Raialos.

On the accompanying map the quartzite has not been shown, for at its greatest thickness, 150-200 feet, it would have to be represented on the map, if dipping vertically, by a line about .01 inch broad. It, or non-calcareous beds equivalent to it, is constantly present at the base of the limestone.

The Raialo limestone is usually a white, massive, crystalline dolomite of a thickness, where measurable, of about 2,000 feet. It passes up conformably into the lowest bed of the Alwar Series, a fine-grained, massive quartzite forming a strikingly precipitous and uneven ridge, which I have called in the descriptive part the "serrate quartzite." Above this quartzite there is in one locality a zone of conglomeratic and gritty beds indicating littoral conditions, and which may even mean a slight unconformity or pause in deposition. In this and the similar case higher in the series, to the north of the Siliberi Kho (p. 43), there is no discordance in the dips of the beds involved and, if these cases mean unconformities at all, they are only local, and the beds underlying have not been folded or denuded to any appreciable extent. Similar slight unconformities have been observed in the Biana hills to the south-east of this, where they are readily recognised, as the Alwars are there more moderately inclined, but they, and those above-mentioned, are entirely different in degree from the profound and persistent unconformity at the base of the Delhis. I lay stress on this because of Hacket's mistaken correlation, in his later paper, of the Raialos with the Aravallis below the great unconformity.

The Alwars extend beyond the Raialos to the west, south and east,—the latter appear to have been laid down in the bottom of a basin the limits of which widened as it subsided, but both have the same markedly unconformable relationship to the underlying Aravallis. Not only is the Raialo limestone quite different in appearance from anything in the Aravallis here or elsewhere,—the latter, as a formation, being remarkably deficient in limestones—but the way in which its outcrop and that of the "serrate" quartzite follow the intricate curves of the Alwars makes it impossible that there can be any discordance between them.

At only one locality, as just mentioned, is there a local conglomerate, unaccompanied by other signs of unconformity, not however at the top of the Raialo limestone, but several hundred feet higher; elsewhere the sections show no suggestion of a break.

The total thickness of the Alwar Series is probably 10,000—13,000 feet; the general facies of the lower portion Alwars. gritty arkose quartzites, is characteristic of shallow water accumulation, but as we pass upwards the quartzites become fine-grained, and micaceous quartzites, representing argillaceous beds, appear, and even a few thin lenticular limestones, showing deepening of the basin of deposition.

In the lower portion, masses of amphibolite, probably altered basic and intermediate rocks, are numerous and of large size, in the form of lenticular phacolites and thick sills, and are often intimately connected with the folding, thickening on the crests of anticlines and thinning on their flanks, where pressure was greater. Of these the uppermost three are probably contemporaneous, the rest are the corresponding intrusives; the highest flow, north of the Siliberi Kho, is associated with a coarse conglomerate denoting land conditions, though an erosion unconformity cannot be detected.

Subsequent in time of injection to the amphibolites are numerous bosses of porphyritic granite, well-foliated and therefore probably brought into position at the time of the folding of the Delhis and as an accompaniment of the same earth-movements.

These were not separated from the sedimentaries by Hackett in his first paper,¹ in which he describes them as "arkose," *e.g.* Harsora, Dadīkar, Khirtal, Pahari and Baggeri (Bajgiri); in his second paper² he maps most of them, but does not distinguish between them and the pre-Delhi granites, though suggesting that there may be two gneisses (*i.e.* granites). Later than the granites, and subsequent to the period of uplift,—for they are never foliated nor sheared,—come the pegmatites. Though quite unimportant here, they attain an enormous development in Torawati and in the Ajmer District. They are the "granite" of Hackett's second paper (*loc. cit.* pp. 282, 297). The more abundant quartz and quartz-tourmaline vein-rocks are possibly the acid residua of the pegmatites.

The Alwar Series passes conformably into the Kushalgarh limestone and that into the Ajabgarh series. The Kushalgarh limestone is about 1,500 feet thick as a maximum, a siliceous, fine-grained rock, conspicuously banded in dark grey and black and is not dolomitic, unlike the Raialo limestone. It also is only locally developed, though more widespread than the Raialo; in the case of the former it is probable that its apparent lateral dying-out is really replacement by slates similar to the Ajabgarhs.

At a varying horizon, sometimes near the base, and sometimes near the top, of the Kushalgarh limestone, comes the hornstone breccia, a rock simulating a bedded deposit but produced probably during the earliest stages

¹ *Rec., Geol. Surv. India*, X, pt. 2, p. 86.

² *Rec., Geol. Surv. India*, XIV, Pt. 4, p. 299.

of folding by compressive stresses acting on the heterogeneous association of thin quartzites alternating with soft slates, a facies in which compression would produce the maximum of shattering with the minimum of folding. There is no evidence that this is of the nature of a thrust fault. The zone of brecciation has subsequently been folded like a bedded rock.

The Ajabgarh Series is a formation in which argillaceous rocks
 Ajabgarhs. predominate, with subordinate impure quartzites and limestones.

The facies shows deeper water deposition than the Alwars, and at certain horizons rapid but not great variations in the conditions, but neither the shallow water characters of the lower Alwars nor beds usually taken as indicating deep water sedimentation are seen.

As their exposures are much scattered and their upper limit has not been observed, the thickness of the Ajabgarhs cannot be even approximately measured but it must be of the same order of dimension as that of the Alwars. The Mandan group of Hacket is really identical with the Ajabgarhs.

CHAPTER III.

PRE-DELHI ROCKS (ARAVALLI SYSTEM).

The base of the Delhi System, resting with marked unconformity on the rocks below, is seen only on the southern margin of the area. The junction of the Delhi and the older rocks has a curiously sinuous course, as, in the earth-movements to which both were subjected, the newer have been folded into the older surface on which they were laid down, in a series of narrow synclines caught up in the underlying mass and separated by broader and less compressed anticlines.

This lobate surface of contact is now cut across in section by the present surface of the land, resulting in the formation of a series of broad embayments in which the scarps of the lowest Delhis overlook the alluvial plain occupied by the older rocks, the bays being separated from each other by narrow synclines representing the nipped-up portions of the folds.

Along with the folding a number of faults have been formed with the same effect.

From west to east, the "bays" are those of Raialo, Baldeogarh, Kho, Baswa, Reni and Ranijo; in the third and last the older rocks are totally concealed.

The pre-Delhi rocks are chiefly granite, with highly metamorphosed sediments, *i.e.*, conglomerates, quartzites, mica-schists, and crystalline limestones in lesser amount, and are seen only in a narrow band along the foot of the Delhi scarp and in a few isolated outcrops in the alluvial plain.

In the western part of the Raialo bay granite is seen imperfectly exposed below the narrow and inconspicuous rise formed by the Raialo quartzite, here the bottom member of the Delhi. At Tholai and 4m. E. by N. of Tholai are elongated quartz outcrops which may be either veins in the granite or highly altered sedimentary quartzites. South of Raialo and Bhangarh the granite forms a slightly elevated and undulating plain, irregularly covered by a thin sheet of sub-recent

calcareous conglomerate from which the granite emerges in places and is visible in stream beds.

It is a very coarse and rather incoherent rock, indistinctly porphyritic, and vaguely foliated in a N.-S. direction, the larger felspar crystals sometimes being fractured. Orthoclase and acid plagioclase, white and much kaolinised, make up the bulk of the rock, with quartz and a very variable proportion of biotite. Grains of apatite occur. (Sps. 23·39—43, sls. 7592-6.)¹ The outcrop of the same granite near Jhiri, faulted far to the north, is finer and more compact and shows under the microscope microcline and micropegmatite in addition. (Sps. 23·41, sl. 7594; 23·43, 7596.)

Pegmatite veins are practically absent, contrasting with their abundance in the granite to the east, near Tatra. Where they occur in the Raialo bay granite, it shows a resemblance to the Tatra variety, being pink and distinctly porphyritic.

Quartz veins are common and so also are the irregular dykes of dark green "trap" (amphibolite), traversing the granite in all directions. These only exceptionally pass into the overlying Delhis and at first sight might be thought to be pre-Delhi in age were it not for the fact that the grits and conglomerates derived from the disintegration of this granite are quite devoid of hornblendic pebbles or grains. Such a tough and resistant material, if of pre-Delhi age, would be expected to be present in the detritus of Delhi age. These dykes are in all probability therefore the feeders of the petrologically similar sills in the Alwar Series near here and are thus post-Delhi in their age of intrusion.

It is noteworthy that this variety of granite forms only small flat exposures at the level of the plain or in stream-beds and never forms "tors" or high, boulder-strewn undercliffs like the Tatra type. It disintegrates readily into felspathic grit. To this is probably due the smaller development of conglomerates in the Delhis here as compared with that in the Delhis of the Reni (Tatra) bay, since the latter type of granite is more resistant and tends to form boulders and pebbles with a smaller proportion of grit and sand.

¹ Numbers thus—'23·39' refer to hand specimens registered in the collections of the Geological Survey of India, and numbers such as '7592' to microscope slides similarly stored and registered.

The small hills 2m. S.E. of Raialo, at Hingwalo, composed of banded crystalline limestone, quartzites and mica-schists, were mapped by Hackett as an outlier of Raialo quartzite capped by Raialo limestone, but the rocks are really vertical and do not resemble the Raialos. Near here are one or two patches of mica-schist, like that of the Hingwalo hills, completely surrounded by granite, but with their exact margins concealed. If the granite is an intrusive mass in the pre-Delhi metamorphics, these would represent portions of the invaded rocks caught up in it.

In the Baldeogarh bay and at Kundal the same trap-veined granite occurs below the basal Delhis, in the latter case associated also with mica-schist.

In the Baswa bay are a number of outcrops of varied metamorphics which are in all probability pre-Delhi, though the sections here lack that perfect clearness which they have in the case where granite forms the chief underlying rock. At each side of this bay dip-faults appear to have shifted a large area of Delhis N. and N.W. of Baswa to a considerable distance northwards.

The largest of these slightly doubtful exposures is that at Rewasa, forming a conspicuous promontory jutting southward from the main scarp of the Alwars and crowned by a ruined fort on its termination. Its main portion comprises very thick foliated conglomerates, made up of large pebbles of white quartz, pale and dark grey quartzite, fine white grit and mica-schist, dispersed regularly through a schistose matrix of biotite and chlorite with good octahedra of magnetite (sp. 22-373). No pebbles of granite or felspar were seen, a distinction from the usual basal Alwar conglomerates.

The foliation planes of the matrix dip W. to N.W. at 70° – 80° ; the pebbles are usually flattened along the foliation and, in certain zones, pressed into lenticles as much as 9" long and $1\frac{1}{2}$ " thick.

North of the conglomerates, next the Alwar scarp, is a band of biotite-quartz-schist, dark green in colour, probably an altered grit and a finer variety of the conglomerate (sp. 22-370, sl. 6898). It is much intruded by a very coarsely crystalline actinolite rock (sp. 22-371, sl. 6899), and large bladed crystals of the same mineral are scattered through it. South of the conglomerate, the hill crowned by the fort is composed of dark-red, vitreous, thin-bedded and copiously jointed quartzite, also with numerous amphibolite veins traversing

it. It strikes towards a line of small isolated hills, of a similar character, near Gudha.

These rocks, quartzite, conglomerate and biotite-quartz schist, belong to a single older series and their relation to the adjoining Alwar grits I consider to be one of unconformity complicated by faulting.

Relation of Rewasa rocks to Delhis.

As stated above, the older rocks have their foliation dip at 70° – 80° W. to N.W., while the Alwar grits, arkose, homogeneous, and much less altered and compressed, stand vertically, striking E.-W., thus the two sets strike practically at right angles to each other, along their line of junction. A short length of the junction was actually seen, a narrow strip of dislocation and shearing in which white grits (Alwar) abut against green foliated grit or biotite-quartz schist (pre-Delhi). In one place this fault has provided the avenue for an injection of amphibolite.

Just south of Rewasa is an exposure of trap-veined granite (like that of Raialo) but its contact with the highly altered quartzite of the hill is covered; the same rock occurs in a well just south of the Raialo quartzite at Todi.

Between Rewasa and Todi are two small outcrops, one of quartz or quartzite, the other of banded silicified limestone; they probably should be classified in the older system.

The base of the Delhis is again seen at the north of the Baswa bay, at Ratanpura. There the Raialos have died out and coarse Alwar conglomerate forms a cliff, resting on fine-grained pre-Delhi mica schists striking nearly perpendicularly to the conglomerate above. South of this is a ridge of conglomerate similar to that of the Alwar scarp and with much the same dip and strike, associated with schists which do not seem to be separable from those at Ratanpura. This second conglomerate may be of pre-Delhi age, or may be the Alwar conglomerate repeated by a strike-fault; the field evidence is inconclusive.

Pre-Delhi metamorphics near Baswa.

On both sides of the railway line, about 2m. N.E. of Baswa, are several small hills of coarsely crystalline ferruginous and mangani-ferous limestone with much pale-green fibrous and dark-green bladed actinolite. (Sps. 22-329, 22-330.) The limestone is banded vertically, the strike running N. or N.N.E., at right angles to the strike of the Alwar quartzites immediately adjoining to the east, a fault probably intervening.

They have intercalated bands of siliceous crush-breccia, and streaks and lenticles of quartz.

In the Rajgarh valley is a narrow ridge of highly metamorphosed grits and quartzites, flanked by limestones, and Metamorphics near Rajgarh. east of this, two small hills which seem, from the extensive excavation round their bases, to have been the source of the Rajgarh iron-ore.¹ They are similar to the Baswa hills, and consist of limestones, brecciated and rich in limonite to the N.W. and S.E., with subordinate quartzites and micaceous beds.

The calcite has been largely removed by weathering, leaving a cellular mass of earthy iron oxides.

From the resemblance in strike, dip and lithological character of the Rajgarh and Baswa outcrops and from their position on an anticlinal axis of the adjacent Alwars, I consider them to be all pre-Delhi in age, and to be exposed by an acute fold or by faulting in the Alwars.

From Golana, at the opening of the Baswa bay, eastwards, the Granite in Reni "bay." basal beds of the Alwar series form a southward-facing scarp, along the lower slopes of which granite is fairly continuously exposed.

The first three miles of the scarp have an E.-W. trend, interrupted by a fault which brings the scarp southwards a couple of miles.

From here the scarp sweeps N.E., then E. and S. again in a wide arc, forming the Reni bay.

The granite is evidently more or less continuous under the sandy plains which slope gently towards the Banganga river, as it is exposed all round the arc and forms several small hills rising like islands from the alluvium at some distance from the scarp.

They are steep and rugged, their sides strewn with enormous rounded blocks, and their summits weathering into the fantastic conchoidal shapes assumed under insolation by granitoid rocks of heterogeneous mineral composition. Along most of the scarp the granite rises to near its top, forming great curved slopes, convex upwards, a bold topography contrasting with that of the granite near Raialo and Baldeogarh. Weathering of Reni granite.

The granite occurring near Parla is very coarsely porphyritic, the large white orthoclase phenocrysts sometimes showing sections

¹ *Gazetteer of Ulwar*, pp. 81 and 183.

up to $4'' \times 1\frac{1}{2}''$. It is rich in biotite, which by occurring somewhat in clusters and planes, produces a rude foliation. The phenocrysts too betray traces of linear arrangement when looked at in the mass, but without persistent direction. (Sp. 22:355, sl. 6888.)

This granite is devoid of pegmatite, but on the scarp north of Parla there are numerous thick veins of quartz running through both the granite and the grits. Most of the veins, when they reach the top of the granite, spread out along the junction between it and the grits, taking advantage of this plane of weakness.

The Parla granite is rich in what appear to be xenoliths of (a) quartz and (b) dark fine-grained quartz biotite rock, with the biotite much crushed. (Sp. 22:354, sl. 6887.)

These may be acid and basic segregations respectively, but they, especially the dark ones, which are the more numerous, have quite even and sharp outlines, which, with the shattered condition of their constituent minerals, leads one to infer their foreign origin. Their sections vary in dimensions from $1' \times 4''$ downwards and are usually somewhat oval. They are present only near Parla.

Along the curving scarp of the Reni bay, the granite varies slightly but not materially, the chief peculiarity being the abundance of ramifying pegmatite veins, in which tourmaline usually occupies a medial position with quartz, orthoclase and microcline nearer the margins of the veins.

At Lada the granite has smaller orthoclase phenocrysts than at Parla, and they are pink instead of white. In addition to orthoclase, quartz and biotite it contains acid plagioclase, microcline and muscovite. Apatite in small grains occurs in all these granites; tourmaline is absent except in the pegmatite veins. Farther along the scarp to the north-east the phenocrysts become somewhat smaller and are occasionally white. About Tatra the granite becomes very dark in colour, owing to an increase in the proportion of biotite, and the large feldspars are often fractured. (Sp. 22:352, sl. 6885.) Farther east, about Bahadarpur, this pressure fracturing has produced a noticeable foliation. (Sp. 22:357, sl. 6890.) The rock of the isolated hills is the same as that of Parla, lacking the pegmatite veins so common in the granite below the scarp.

Amphibolite veins were not observed in the pre-Delhi rocks, east of Rewasa; this is to be expected as the sills in the Delhis themselves are much fewer than near Raialo and Baldeogarh, almost absent in fact.

Absence of amphibolite in Reni granite.

It should be clearly pointed out that the pre-Delhi granites and associated pegmatites are quite distinct in age from the petrographically similar granites and pegmatites intrusive in the Alwars.

Distinction from later granites.

The Delhis, Raialo quartzite or Alwar Series as the case may be, rest on the pre-Delhi granites with a great unconformity and are derived in part from their disintegration.

The relationship of the pre-Delhi granites to the metamorphic sedimentaries of Rewasa and Hingwalo can only be conjectured; the various outcrops are scattered and isolated and in no case is a junction visible, so direct evidence is not available. Outside this area, however, an extensive series of pre-Delhi schists in southern Jaipur is found to be invaded by similar granites and pegmatites, also anterior, in their period of intrusion, to the basement beds of the Delhis. Of course the great stretches of all-concealing alluvium make it impossible to show that these schists are of the same series as the Rewasa rocks, but both are older than the Delhis and in the absence of contrary evidence it may be considered at least probable that they are the same, and that by analogy the granites of Raialo, Reni, etc., are also intrusive masses in the metamorphics represented by the Rewasa rocks.

I have been unable to decide whether the pegmatite veins were injected into the Reni granite subsequent to its solidification or are segregation veins formed during the later stages of cooling, a partial residue having remained fluid after the bulk of the minerals had crystallised out. The abundance of tourmaline in the pegmatite, though absent from the granite, and the fact that similar tourmaline pegmatites are found injected directly into the schists of southern Jaipur, causes me to favour the former view, that the veins are extraneous and of a later age than the granite, though still pre-Delhi.

Relation of pegmatite to granite.

The pre-Delhi rocks here correspond to the gneiss mentioned by Hacket;¹ in his later paper he has not differentiated between these and the later gra-

Gneiss of Hacket.

¹ *Rec., Geol. Surv. India*, X, pt. 2, p. 86.

nites intrusive in the Delhis, suggesting however that there may be two gneisses.¹

By referring to the schists, etc., as pre-Delhi I have avoided appearing to assume that they all belong to the Aravalli System. The thick conglomerate near Rewasa indicates that we have a break in the succession in the pre-Delhi rocks, for the pebbles of the conglomerate, if it is epiclastic, must have been derived from the degradation of older rocks exposed near at hand while it was being accumulated. Further work in more favourable areas may show that the pre-Delhi rocks may be divisible into several groups of different ages of which the Aravalli System may be one, but at present we can only say that the non-igneous pre-Delhis are not necessarily of one age, though they may in whole or in part belong to the system which we call Aravalli.

(Pre-Delhi granites—Sps. 22-352-8, sls. 6885-91, sps. 23-39-43, sls. 7592-6.

Pre-Delhi metamorphics—Sps. 22-320, 22-329-30, 22-369-74, sls. 6859, 6897-6900.)

¹ *Rec., Geol. Surv. India*, XIV, pt. 4, p. 299.

CHAPTER IV.

RAIALO LIMESTONE AND QUARTZITE.

The Raialo Series, the lowest division of the Delhi system, consists of a thin group of quartzites, the Divisions. Raialo quartzite, resting directly on the pre-Delhi granite described in the last chapter, and passing upwards conformably into a much thicker limestone, the Raialo limestone, which again is conformably succeeded by the lower beds of the Alwar series.

The Raialos are exposed only in the Raialo, Baldeogarh and Kho "bays," and in the N.W. corner of the Baswa "bay," and would appear to be a local, though Extent. thick, deposit, since to the east and west the Alwar series is found to rest directly on the pre-Delhi rocks, while to the south the Raialos thin out and the Alwar Series extends beyond them on the pre-Delhi granite. How far they are present to the north of their visible outcrops it is impossible to say, as the Alwars and younger divisions of the Delhis conceal all below them.

In southern Jaipur also, where extensive sections of the unconformable junction between the Delhis and the pre-Delhi schists and granites are exposed, the Raialos are absent.

The form of the granite surface upon which the Raialo quartzite and limestone were laid down has been completely changed by folding, but the Raialos Surface on which deposited. overspread only the softer and less coherent granite of the type found at Raialo and are absent from above the harder and more resistant Parla variety and from localities where schists occur. This suggests that the softer granite gave rise to a hollow (of denudation) in which the Raialos were subsequently deposited.

(a) The Raialo quartzite.

On the accompanying map I have not indicated the quartzite since it occupies only a very narrow belt too Outerop. small to indicate on the scale, and is invariably present at the base of the limestone.

It is referred to by Hacket¹—"the quartzite, compact in texture, regularly bedded and grey in colour, rests upon the gneiss (*i.e.*, the pre-Delhi granite) and dips under the limestone." The outcrop consists of a low, narrow ridge rising above the plain formed by the granite, and usually dipping away from the granite at high angles.

The quartzite is quite insignificant as compared with the Alwars, its thickness probably nowhere exceeding 150 to 200 feet.

Thickness. The ridge or scarp is much interrupted by unequal denudation, by small dip-faults and by the considerable Irregularity of outcrop. variation in the thickness and character of the beds, attributable to their deposition on an uneven floor.

Where best exposed and thickest the quartzite is seen to be divisible into two portions separated by a bed of limestone similar to the Raialo limestone.

Sub-divisions of the quartzites.

The lower part, next the granite, consists of quartzose grits and thin-bedded quartzites with argillaceous partings. They are grey in colour and distinctly bedded, even ripple-marking being observable in places, but usually they take the form of coarsely granular quartz-schists and slaty quartzites with wavy foliation, parted by layers of mica-schist. (Sp. 23-53, sl. 7604.) The upper zone is of white or pale-grey, compact, vitreous quartzite, very similar to the Alwars, in distinct beds several feet thick, showing little structure except jointing. (Sp. 23-54, sl. 7605.)

The character of the beds varies rather rapidly along the strike, for instance at Raialo the lower grits are absent and the whole thickness exposed is of massive sparingly jointed and indistinctly bedded quartzites, while north of Thali they die down to a very thin scarp with several quartzite layers in the limestone.

Horizontal variation of quartzite.

In the disconnected outcrop east of Jhiri the quartzites are schistose, and when followed northwards become more micaceous and less siliceous,—mica-schists in fact,—which are preserved from total denudation by thin quartzite ribs.

In general the Raialo quartzite is copiously jointed, this character combined with the well-developed bedding or Jointing. lamination producing outcrops which are almost smothered in their own debris.

¹ *Rec., Geol. Surv. India*, X, p. 85.

Dip is always high, from 40° to verticality; in one place the quartzites are inverted, dipping S.W. under the granite.

Dip.

The strike is sinuous and interrupted by dip-faults.

Though granite is almost always to be found in wells or on the surface within a few yards in front of the Raialo quartzite scarp, in only two places was a junction seen, so debris-covered is the base of the scarp and so little does the granite rise above the level of the plain. At a point $\frac{1}{2}$ mile N.W. of Kalajpuri (near Raialo) the quartzite is represented by quartz-mica schist and biotite schist into which the granite seems to merge without any definite boundary; the Raialo limestone (ferruginous) is seen above the schists a few feet away. There is no trace of an unconformity conglomerate.

In the other section, a small stream-bed $1\frac{1}{2}$ miles N.W. of Thali, the pre-Delhi granite is topped by 6 inches of soft material, kaolinised granite, then again 1 foot of coarse soft grit, rounded quartz grains in a kaolinitic matrix, lying above the disintegrated granite layer, and followed upwards by the quartzite.

On my first examination of the Raialos the absence of a basal conglomerate and the irregularities in the Raialo quartzite suggested the possibility that the granite might be intrusive in the Raialos, but a subsequent visit quite convinced me that this theory was untenable and that the Raialo quartzite lies on the eroded granite surface.

I had seen, in the Biana-Lalsot hills to the south, that the absence of a basal conglomerate is no disproof of unconformity, and re-examination satisfied me that the irregularities in the quartzite were due to varying conditions of deposition on an uneven surface and near a shore-line. There is a total absence of signs of special thermal metamorphism by the granite, such as pneumatolytic minerals, and there is no modification of the texture of the granite near its margin, nor does it send off apophyses or pegmatite veins.

The absence of a conglomerate is probably due to the easy disintegration of this granite; further east where the Alwars rest directly on a much harder and more coherent variety, pebble and boulder beds derived from the subjacent granite are in great force.

The ancient shore-line had an approximately E.N.E.-W.S.W. trend through Tholai, Bhangarh, Baldeogarh and Todi; south of this line the Raialos are seen to have died out by thinning and the Alwars rest directly on the granite.

Southern limit of Raialos.

The southern limit of the Raialos is preserved in the closely compressed synclines between the "bays"; in the northern parts of the "bays," where the strata are anticlinally curved, the Raialos are thicker and represent material deposited several miles from the shore line; north of this they extend for an unknown distance under newer beds. (Raialo quartzites—Sps. 23·53-4, sls. 7604-5.)



FIG. 1.—Diagrammatic N-S. section between the Raialo and Baldeogarh "bays" showing extension of Alwars beyond the Raialos on the pre-Delhi granite.

(b) The Raialo limestone.

North of the low and insignificant scarp formed by the Raialo quartzite, and stratigraphically immediately above it, are found several large expanses of the Raialo limestone, into which the quartzite passes up sharply but conformably. N. and E. of Kho also there are several exposures, parts of a much faulted anticline in which the limestone alone is seen.

Outcrops.

Normally it is a pure white, hard and saccharoidal crystalline marble with stratification invisible or very obscure and with jointing rather sparingly developed. (Sps. 23·55-63, sls. 7606-12.) Crystals of pale green tremolite, often of large size, are plentifully developed and are generally confined to planes which may represent the situation of more argillaceous layers in the original rock; actinolite is found in ferruginous localities and near intrusions of hornblende rock.

Description.

The limestone seems to be an almost pure dolomite. A quantitative analysis was not carried out but three different tests were applied, (1) boiling the powder for 10 minutes in cobalt nitrate solution (dolomite is unchanged, calcite becomes pale blue and aragonite pale violet), (2) treating both chips

Dolomite.

and microslides with ferric chloride for 1 minute and then with ammonium sulphide (dolomite is unchanged but calcite becomes intensely black) and (3) Skeat's method¹ with Lemberg's solution as modified by La Touche.²

All these, each applied on several distinct specimens, showed that calcite was present only in occasional scattered grains.

In the Kushalgarh limestone, on the other hand, there is very little dolomite.

Besides the pure white variety, yellow, pink and brown (ferruginous) modifications are met with. The pink is quarried near Baldeogarh. A remarkably pretty pale grey kind, rather fine in grain and even in colour and texture, is seen $1\frac{1}{2}$ miles N.W. of Raialo. The white marble has been quarried to a slight extent at many places distributed over its outcrops, but only near the villages of Jhiri and Raialo has much been worked and then only in shallow excavations hardly going below the surface zone of open jointing.

As a rule no strike can be detected, save a rude and variable linear outcropping made visible by weathering, and perhaps rather a pressure effect of folding than an original structure.

At many places along its upper margin below the base of the succeeding Alwar quartzites, it is seen to contain siliceous layers which project in consequence of differential weathering. These layers have a curious scalloped or festooned outline, resembling Persian script (Plate 1, fig. 2), as if lateral pressure had caused them to buckle equal distances into corrugations concave in one direction. Though at a first glance similar to the very characteristic banding of the Kushalgarh limestone, this is different, for in the more usual type of puckering in the younger rock, the bands (also due to alternations of hard and soft layers) are of approximately equal thickness, whereas here the outstanding siliceous layers are separated from each other by spaces of three or four times their width, occupied by less resistant material.

Near its top the marble is largely converted into a yellow or brown cherty substance, quite probably due to the downward transference of silica from the thick quartzites above.

¹ *Bull. Mus. Comp. Zoology*, XLII, p. 103.

² *Mem., Geol. Surv. India*, XXXIX, pt. 2, p. 189.

On the large expanse of limestone to the N. and E. of Raialo, are numerous small, dark-coloured and rugged hills diversifying the flat and soil-less plain formed by the limestone. These are composed of irregular masses of iron-ore, probably metasomatically replacing the calcite and dolomite, and varying from marble coloured brown by hydrated iron oxide, to pure hematite. Owing to their superior resistance to denudation these ferruginous masses always form hillocks and are the only eminences on the Raialo limestone outcrops. Their economic importance is indicated below (p. 118).

The iron and copper mines of Bhangarh occur near the top of the limestone, the copper in the cherty zone above-mentioned and the iron partly in the limestone, as a replacement or impregnation, and partly in some slates brought against it by a small fault.

As bedding-planes are absent or obscure, the thickness of the limestone cannot be exactly measured but may in places be roughly estimated, for instance east of Jhiri and north-east of Bhangarh, where the Raialo quartzite below and the Alwars above have nearly the same dip, and the width of the limestone outcrop remains approximately constant for several miles along the strike. Assuming that the inclination of the limestone is constant along a section at right angles to the strike and that the dip is the same as in the stratified quartzites at each end of the section, a thickness of about 2,000 feet is arrived at.

Elsewhere than at these localities the limestone forms broad expanses, irregularly and rapidly varying in width, for which inconstant and rolling dips, as well as faulting, are doubtless chiefly responsible.

Upwards the limestone passes conformably into the lowest beds, quartzites, of the Alwar Series.

(Raialo limestone—Sps. 23·55-63, sls. 7606-12.)

CHAPTER V.

ALWAR SERIES.

General Description.

The Alwar Series consists predominantly of an immense thickness of compact quartzites, grits, and conglomerates, with very subordinate argillaceous beds and impure limestones. Several bosses of intrusive granite and pegmatite veins also occur and there is a great development of sill-like masses of hornblende-rock, probably highly altered dolerites. These are chiefly intrusive, but a few may represent effusive lava flows. I have assigned a chapter (Chap. IX) to the description of the igneous rocks, but as the hornblendic sills are most intimately associated with the Alwar quartzites I have found it necessary, in order to avoid repetition and confusion, to treat of their mutual field relations in the detailed account of the Alwar outcrops which follows, relegating questions such as their structure and their origin to Chapter IX. The same holds good, only to a lesser extent, regarding the granite and pegmatite.

In the ensuing remarks I refer to these basic rocks as amphibolite,¹ a term which accurately expresses their mineral composition, or as "trap," a time-honoured and useful field name.

This general description is an attempt to represent the main facts about the Alwar Series in as concise a form as possible. In an account of rocks which vary so greatly and which cover such an extent of country, it is useful to collect their more widespread and commonly met with characteristics, leaving unusual and less important particulars to be mentioned in the section in which the exposures are serially described. Though the remarks below will be found to be considerably modified and qualified by the detailed description, they may be taken as presenting, fairly accurately, the chief features of the Alwar Series.

In passing from the north of the area southwards to where the base of the series is seen along the southern frontier of Alwar State, a transition is noticeable from quartzites to grits often felspathic

¹ *Harker's Petrology*, p. 325, 3rd Ed.

and conglomeratic, a change which is accompanied by a decrease in the proportion of quartz which the rocks contain, and an increase in other detrital minerals, microcline, orthoclase, kaolin and tourmaline.

As the junction of the Alwars with the underlying Raialo or pre-Delhi rocks is not exposed except in the south, and as recognizable horizons are absent, we cannot tell whether the lower beds of the Alwars come to the surface towards the north of the area or not, and so are unable to ascertain if this change from highly siliceous quartzites to arkose grits affects the whole of the series, or is merely an appearance due to the basal coarser beds being concealed northwards by finer quartzites overlying them. The probability is that the transition is a reality and is accompanied by a diminution in the thickness of the beds as they are followed southwards, betokening that the pre-Delhi land surface from the denudation of which the immense thickness of the Alwars was derived, lay somewhere to the south.

Generally speaking the quartzites are white, pale grey or pale pinkish-purple in colour, more or less streaked and mottled with brown and red according to the amount of iron oxide which coats the grains. The arkose grits are pink or yellow from the often large amount of orthoclase and microcline which they contain.

In the quartzites, some of which are probably recrystallised quartz grits, quartz, usually in a mosaic of interlocking allotriomorphic crystals without interstitial material, is by far the predominant mineral and normally shows no sign of the original rounded grains, or of secondary growth round them.¹

Small fragments of muscovite and tourmaline are common and are probably detrital, and biotite is sometimes present, also iron oxides and pyrites. Much sillimanite in groups of needles ('Faserkiesel' or 'quartz sillimanitisé') occurs near the granite intrusion west of Alwar City (sp. 22:331, sl. 6868, Pl. 14, fig. 2).

The quartzites are nearly always vitreous, breaking with sub-conchoidal fracture and sharp and splintery edges. In hand specimens they show little or no trace of their clastic origin.

¹ *Harker's Petrology*, p. 295.

The arkose grits and conglomerates contain the minerals of the granites which underlie them and from which they have evidently been derived—quartz, microcline, kaolinised orthoclase, tourmaline and muscovite.

In structure they vary from hardened but otherwise little altered sediments to rocks which, with their compressed and sheared pebbles, can be distinguished only with difficulty from gneisses.

The quartzites are abundantly jointed, more or less rectangularly (Pls. 3 and 4), the amount and the irregularity of the jointing seeming to be in proportion to the tilting which the beds have undergone. This, aided by their rather definite bedding, leads to the formation of bare smooth precipices, the faces of which coincide with the dip-slopes of the highly inclined strata, while the joints are clearly seen as lines or clefts on the faces. These precipices are breached at frequent intervals by deep V-shaped gorges at right angles to the strike, giving rise to a striking and highly characteristic feature of the Alwar hills.

At the foot of any high outcrop of quartzite there is always a great scree of fallen fragments, on which the maximum observed "angle of repose" was 32°. (Pls. 3, fig. 1, 4, fig. 1.)

The blocks are of all sizes and are angular, weathering with only a very thin crust slightly darker than the fresh rock. Owing to the homogeneous and impervious nature of the quartzite, the disruptive action of water and the atmosphere has little play except along joints and bedding-planes, and it is left to changes in temperature to effect the rounding of the fragments that have lain for some time detached from their parent crags.

Among the grits, which are less closely jointed and stratified, weathering tends to produce much more rounded outcrops. They break down with greater ease into sand and usually carry a thicker weathered crust than the quartzites, owing to the varying coefficients of expansion of their constituent minerals under alternate heating and cooling, giving rise to a porous surface layer which allows the entrance of water; they often form domes and "tors" akin to those of granite but on a smaller scale.

Both quartzites and arkose grits are rather thickly bedded, or in beds of medium thickness. Open planes of stratification occur usually from 2 feet

to 6 feet apart, often less, but the character of the rocks is the same over a considerable number of beds, *i.e.*, there is little of the intercalation of soft argillaceous bands between the quartzites, which is such a marked feature of the Ajabgarhs. (Pls. 12, fig. 2, 13, fig. 1.)

Softer zones, more micaceous or argillaceous, occur of course, but they comprise sets of numerous beds all having much the same character, and frequently differing little in appearance from the usual hard beds, rather than definite slate or schist layers between the normal quartzites. They are usually micaceous flagstones. To these differences in composition are due the parallel ridges and valleys so largely developed in the Alwar hills, to which the names 'mála' and 'chhínd' are locally applied.

In the quartzites ripple-markings are common (Pl. 4, fig. 2) with less frequent sun cracks. The former are well
 Ripple-markings. seen on the path leading up to the Alwar Fort, though one might expect to find them obliterated in strata which have been so highly folded as to stand almost vertically.

The general strike is about N.N.E.—S.S.W. The stress which
 Strike. has buckled the rock masses acted in a direction about W.N.W.—E.S.E., but the result has been the production of countless irregularities and warpings which tend to obscure the general trend, and the rocks may, for short distances, strike to any point of the compass.

Perhaps the most striking feature of this tract is the high in-
 Dip. clination at which the strata nearly always stand. About 70° is the most usual (Pl. 4, fig. 1), verticality is quite common (Pl. 5, fig. 2), overfolds are found on the W. or N.W. sides of most of the synclinal valleys, while the lowest dip recorded, except for short distances on the crests of anticlines, was 10° — 15° near Saroli (Pl. 5, fig. 1).

The Alwar series rests conformably on the Raialo limestone where that is present (pp. 26—28); where it has not been deposited the Alwars lie unconformably on the pre-Delhi rocks (pp. 15—21).

They pass upwards without a break into the Kushalgarh limestone.

As the Alwars are conformably succeeded by softer rocks which weather easily, the top of the series is almost everywhere shown by a precipitous dip-slope rising over the low country occupied by the newer rocks or by alluvium. Similar dip-slopes occur in

most of the valleys eroded in weak zones in the Alwars, so we may say that the striking scenic features of the Alwar hills are caused by *dip-slopes, not by scarps.*

Except in the south, where the base of the series is visible, it is impossible to estimate its thickness.

In measuring a number of sections between their base and the margin of the Kushalgarh limestone, which succeeds the Alwars conformably, a maximum thickness of 13,000 feet was obtained in two cases, N.W. of Ratanpura, and N. of Rewasa; two other measurements gave about 10,000 feet, and near Jamroli and Tatra to the east, where the series is certainly much thinner, 6,000 and 4,000 feet respectively. There may be considerable sources of error in the variation in dip from point to point on long sections in highly folded rocks and in the fact that the point of junction with the Kushalgarh limestone has in the above cases to be interpolated, but 10,000 to 13,000 feet may be taken as the thickness.

Quartz veining is rather infrequent in the Alwars, except where they have been much crushed, as for instance in parts of the hornstone breccia.

Injected veinlets of quartz-tourmaline rock (sp. 22·364-5), which is perhaps an extreme modification of pegmatite, are commoner. Tourmaline, in fact, is a well-distributed mineral in the Alwars, for besides its occurrence as derived grains in the rocks, it is frequently found along joint planes as prismatic crystals in the quartzite on either side, usually with their bases on the joint; it has probably been introduced from acid intrusives.

(Alwar Series—sps. 22·331-349, sls. 6868-82, sps. 23·66-80, sls. 7615-28.)



FIG. 2.—Tourmaline crystals near joint in quartzite.

¹ Harker's *Petrology*, p. 294.

Detailed Description.

Taking the area as a whole the Alwars may be said to form a strip of hilly country running from Delhi S. by W. to Noganwa, with sundry Ajabgarh outcrops to the east, and farther east again a group of Alwars surrounding Kaman. About 15 miles N. of Noganwa and to the W. of it, a parallel but much broader band commences, which south of the latitude of Alwar City widens out into the wild and intricately folded hill-mass which occupies most of the southern part of Alwar State and terminates along that state's frontier with Jaipur.

The Ajabgarhs are found E. and W. of this and in synclinal valleys in its midst; two of these, the valleys of Ajabgarh and the Deoti lake, running N. and S., almost divide it lengthways into three portions, and the Kushalgarh valley crosses it from E. to W.

As a general rule the Alwars form hill-masses along anticlines and valleys along synclines; in the latter, if the axes have pitched low enough, the softer slates of the Ajabgarh Series are preserved.

In the following description I shall commence from Delhi, proceeding with the reader southwards to where the base of the Alwars is seen resting unconformably on the pre-Delhi granite and schists or conformably on the Raialo limestone, then westwards to the limit of the area under discussion and lastly northwards to join up with the part described on the southward journey.

The historic 'Ridge' of Delhi forms the most northerly prolongation of the Alwar Series and likewise of the Delhi System. South from Delhi to near Sohna extends a large plateau which is probably the vestiges of an isoclinal anticline. The strike varies from N.-S. to N.E.-S.W.; dips are high and somewhat irregular, in the northern part usually towards the E. and S.E. (contrary to the usual rule in these isoclines), in the south to W. and N.W.

The maximum elevation of this plateau, 1,000—1,100 feet above sea-level or 400 feet above the alluvial plain of the Jumna, occurs near its southerly limit; northwards its surface gradually falls till at the Mutiny Memorial on the Ridge, the height is only 794 feet, 80 feet above the plain. Its continuity is broken by wide expanses of alluvium, strewn with the ruins of Toghkakabad and the earlier

of the "Seven Cities," but in a broad sense it can be considered as a plateau.

Though viewed from below it appears to be a flat tableland (perhaps an elevated plain of erosion), when ascended it proves to be in detail very uneven, trenched by ramifying ravines which trend mainly along the strike and are separated by low ridges representing slightly harder beds. Between these projecting ribs of rock there is frequently a fair amount of dry sandy soil, supporting thin grass and sparse thorny bushes, and even in a few places patches of cultivation and small tanks for watering cattle. (Pl. 14, fig. 1.)

The rocks themselves are more thickly bedded and darker than the usual Alwars; the shaly bands characteristic of the Ajabgarhs are quite absent and in the individual beds stratification is almost eliminated; only here and there slight colour differences show it. Jointing is rectangular and sparse.

They are quite vitreous and usually coarsely crystalline (granitoid) in texture and no clastic structure can be seen.

Owing to the slight amount of impurities they contain, they weather with a thickish crust into sub-rounded blocks; some of the ferruginous beds, in which iron-oxides occur between the grains, disintegrate to a coarse sharp grit, in a similar manner to granite, but composed only of quartz. In the subsoil, derived probably from these ferruginous beds, are numerous pea-like concretions of limonite (sp. 24634) which at first sight I took for laterite pebbles, but on investigation found to be formed in the soil and to enclose sand grains. They are seen chiefly near tanks, where the subsoil has been excavated and subjected to rain-washing.

In several localities, thick pegmatite veins occur, soft and incoherent, consisting of white kaolinised orthoclase, bleached biotite, a little quartz and very scanty tourmaline; they are worked for kaolin (khari), rock crystal (bilór), and mica (abrak or bhódal).

These veins are probably more numerous than appears, as even those which are quarried are found in hollows and are covered by soil and rock debris washed in by rain.

The above described plateau terminates about 5 miles E. of
 Hills W. of Sohna Sohna. West of its end is the commence-
 and the Alwar-Gurgaon ment of a range of hills which runs uninter-
 boundary range. ruptedly south to Noganwa and for a long
 distance constitutes the boundary between Gurgaon District and
 Alwar State.

The Alwar quartzites which form them are less altered than those of the Delhi hills and show a certain approximation in lithological character to the Ajabgarhs. They differ from the typical Alwars in being more thickly bedded, especially on the west side, in being more argillaceous and ferruginous (therefore darker and softer), and in the occurrence of thin bands of siliceous slate and mica-schist, always, however, quite subordinate in amount to the quartzites.

At the extreme N.E. point of the range, near Bhundsi, there is a projection from the main ridge in the form of an anticlinal dome, in which dips are unusually low, 10° and upwards, and the strata are little altered—are more coarse-grained, rusty, micaceous sandstones than quartzites. Due west of this, on the other side of the ridge, is a larger and more irregular promontory in which the inclination of the strata is very variable and frequently cannot be made out. It is probably an alternation of anticlines and synclines, more closely compressed, striking N.E.—S.W. In the ravine just south of Bhundsi, the rocks are penetrated by ramifying veins of a pegmatite, almost entirely of muscovite, with a little quartz. Just before my visit it had been prospected for mica, unsuccessfully.

At Kasan, a “ghát” or pass through the hill is formed by the removal, by natural and human agencies, of a thick micaceous pegmatite. It is about 15 feet wide, with irregular sides determined by the jointing of the country-rock, quartzite, and having sheaves of mica sticking into the quartzite of the walls. The trench crosses the strike obliquely and veins of the pegmatite run out along the softer beds; these are worked to supply the small local demand for mica. The kaolin of this intrusion, formed by the decomposition of the felspar, is pink instead of white.

In all the above pegmatite occurrences tourmaline is scarce or absent, while mica is abundant; it seems to be a general rule that in these pegmatites in the Delhi System, tourmaline and mica are never both present in considerable amount; if either is conspicuous the other is absent or in very subordinate amount.

In a few instances quartz-veins occur, and brecciation *in situ*, with introduction of iron-oxides in the interstices between the smashed-up fragments.

From its northern termination southwards to about Nuh, the range is broad and complex in structure, lying along the axis of an anticline in varying degrees of parallelism to it.

At Sohna the ridge twists sharply and the beds are highly altered. Here a road crosses the hills, showing a striking case of how the sandy alluvium is piled up on the windward, *i.e.*, west side of a transverse barrier (p. 102). On the east side the road ascends the face of the ridge in zig-zags to about 350 feet above the level of the plain, but on reaching the top alluvium is met with after a descent of about 50 feet. From the junction of rock and alluvium there is a gentle descent to the normal level of the plain some miles farther on. There is thus a difference in the height of the alluvium on each side of about 300 feet. The same thing is seen on a smaller scale $1\frac{1}{2}$ miles S.E. of Kasan, in both cases the trend of the hills forming a natural funnel for the prevailing wind carrying the sand.

S.W. of Nuh the range is joined by an arm on the west, a narrow valley filled with blown sand dividing them.

They again diverge widely near Tijara but unite N.W. of Firozpur. The interval between them is due to the erosion of a zone of slates or other easily removed beds, which vary in the amount of their dip from place to place and so by their altering width of outcrop cause the quartzites on each side of them to approach or recede. These thin out rapidly southwards. From Nuh to Firozpur, dips are regular, to W. and N.W. The axis of the anticline lies to the east of the ridge, passing through the quaquaversal dome at Santhawari, so the western limb alone is visible. Near Firozpur the eastern limb of the anticline re-appears and to the termination of the ridge at Noganwa the axis passes midway along it.

To the west of the northern part of the range, near where it bifurcates, are a number of scattered hills contrasting with it in lithological character. The beds are vertical, striking N.S., and are highly typical pale coloured Alwar quartzites, highly vitreous and sometimes foliated.

The top of the ridge is very even and is lower than the usual upper level of the Alwars, about 1,500 feet above sea-level in the south, gradually falling northwards to about 1,200 feet. So flat is the top that a paved causeway ran along it for miles, connecting the various strongholds of the Mewatti chiefs who were such a thorn in the flesh of the Delhi emperors.

Passing S.E. from the Noganwa end of the Alwar-Gurgaon boundary hills, we first encounter a belt of Ajabgarhs and beyond that the Alwars outcropping around Kaman.

The Alwars in N. Bharatpur.

These comprise an oval anticlinal dome 2 miles W. of Kaman, and, intervening between this and Kaman, a narrow, twisting ridge with an average S.W.—N.E. strike. The latter is connected to the south with a parallel and much broader band E. of Kaman, the two together forming an imperfect ellipse, perhaps a syncline. In concordance with the mutual approximation in character which seems to take place in the Alwars and the Ajabgarhs to the east of the central area, these exposures show some resemblance to the Ajabgarhs. They consist mainly of fine-grained somewhat schistose quartzites, dark in colour, usually thin-bedded and slaty. Dips are high and irregular, and the rocks are much altered, almost cherty. Siliceous slates are conspicuous along the S.E. margin of the ellipse. The anticline west of Kaman is of coarse-grained, dark, quartzitic grits, obscurely bedded. As a whole, the form of the hills is that typically produced by the Alwars.

The main mass of the Alwar hills commences with scattered ridges and isolated peaks which broaden and close together south-west along their strike into the less denuded hilly region west of Alwar City.

East of the railway line, which runs between Alwar City and Khirtal along a valley excavated in a syncline, are two parallel anticlines terminating near the railway by sudden steep pitching of their axes. At their ends, especially the south-west, their anticlinal structure is clear, but midway along them they are closely pressed together and form the usual north-westerly dipping isoclines. They are deeply trenched by narrow longitudinal valleys excavated along micaceous zones and separated by almost vertical ridges, giving rise to a topography which faithfully displays the geological structure.

Ripple-markings and false-bedding are common, and often along the joint-planes thin films of hematite and black dendritic markings of manganese oxide are seen.

In the isolated hill of Fatehabad-Palpur is a very striking instance of trap-injection. Just south of Palpur there is a high bare cliff exposing in section rectangular slabs of quartzite and irregular fragments of all sizes, jumbled together in a dark green matrix (sp. 23-97, sl. 7645). The quartzite fragments have hornblende pervading them in fine lines along the bedding, and in blebs and trans-

verse cracks, but their margins are quite sharp and their angles unrounded. (Pl. 8, fig. 1.)

The superficial resemblance of the outcrop to some varieties of the hornstone breccia is marked, except that the matrix is trap instead of ferruginous silica. Under the microscope, hornblende, with sphene, is seen enclosing pieces of a rock composed of quartz and acid plagioclase, with scattered grains of hornblende and sphene. Both arkose and amphibolite are even grained and granitoid, without any finer material at their mutual junction. (Pl. 20, figs. 1 and 2.)

There are a few outcrops of granite, of the type intrusive in the Alwars, near Khirtal and near Bajgiri (Baggeri of Hackett),¹ but their junctions with the quartzite are concealed.

West of Khirtal are the Mandawar hills, notable for the low
Mandawar Hills. dips of the strata, in general to W., S.W.,
and S., with numerous minor rolls and areas
of horizontality. The normal vitreous Alwars are absent; instead we have micaceous quartzite flagstones. The mica is muscovite and is probably metamorphosed argillaceous material, not detrital; tourmaline is very common, in rock near open joints and in quartz veins, as well as in derived grains.

The low dips favour the occurrence of springs, which are rather unusual in this region. At the south end of the Mandawar hills dips steepen and outcrops narrow down to broken ridges connecting with the synclinal beds at the north end of the Delawas valley.

There are several amphibolite bands, one of which is seen to bifurcate $1\frac{1}{2}$ miles S. of Titherpur. There are other evidences of their intrusive nature. For instance E. of Beroj, the road from Hamirpur is cut in a trap band for about 500 yards at the foot of a hill, this band running perpendicularly to the strike of the quartzites well exposed on the crest above. The actual junction is debris-covered. Another similar juxtaposition is seen a mile to the S.W.

On the other hand, at Beroj is a lengthy outcrop of an altered rock in which much epidote appears, with hornblende. Quartz is present and microcline in bands, tourmaline, sphene and a little calcite. This rock is distinctly bedded, weathers in the manner of a limestone and, in short, seems sedimentary rather than igneous. It may be a highly altered arkose tuff.

Near Beroj and Titherpur are also two intrusions of very coarsely-crystalline tourmaline pegmatite.

¹ *Rec., Geol. Surv. India*, X, p. 86.

Between the head of the Delawas valley and the railway is an oval anticline traceable for some sixteen miles along its strike (N.N.E.—S.S.W.) and having a maximum breadth of about six miles. On the west its beds dip towards the Delawas syncline, to the east it is separated, by a narrow synclinal arm of that valley, from the anticlinal mass on which the Alwar Fort is built.

This large anticline is somewhat pear-shaped in plan, its greater breadth to the south being due to the presence of an intrusive mass of granite which bulges the strata out on either side.

The trend of the ridges round the granite as shown on the map suggests lines of flow curving round a phenocryst in a microscope section of a rhyolite, or the structure of "flaser gneiss."

In its northern half, the central parts of the anticline are much denuded, but around the granite intrusion the quartzites are much hardened and compressed into an isoclinal fold, so that their superior resistance has enabled them to persist in the form of an irregular tableland scored by strike valleys.

The granite is what Hacket¹ calls "arkose rocks" but its true nature is quite unmistakeable, (see p. 93) as is its intrusive relation to the surrounding rocks (sps. 22-350-1, sls. 6883-4).

For several feet near its edge it becomes much finer grained and very markedly schistose, passing gradually into a micaceous quartzite, the mica of which may have been introduced from the granite.

Being an easily weathered rock it forms by its removal an almost circular valley filled with alluvium and surrounded by high hills of quartzite, the granite outcropping round the base of these in huge curving surfaces and enormous loose boulders, sloping up to the precipitous quartzites above.

Along the foot of the hills S.W. of Dadikar the quartzites have been thermally metamorphosed into sillimanite-quartz schist ('Faserkiesel' or 'quartz sillimanitisé,' (sp. 22-331, sl. 6868) so full of bundles of sillimanite needles and muscovite as to be quite friable, producing a very "sharp" sand used by local tinsmiths to clean copper vessels preparatory to tinning. Uphill this rock appears to pass into normal quartzites, and its actual junction with the granite is concealed.

¹ *Rec., Geol. Surv. India*, X, p. 86.

At the extreme south of the granite boss $1\frac{1}{2}$ miles S.W. of Dadikar, is another evidence of thermometamorphism—a band of pure white saccharoidal marble about 40 feet wide, which has been opened up to some extent (sp. 22-307). It ought to form an excellent ornamental building stone, but is somewhat spoiled by open joints, which defect would probably be overcome by deeper excavation.

What appears to be a small intrusive vein of tremolite-biotite rock occurs in the marble, running mainly along the strike; some of the amphibole crystals are of very large size, and I was shown a large crystal of sphene said to have come from this (sp. 22-361). Immediately to the N.W. of this marble and running parallel to it, is a thin band of coarsely crystalline black biotite rock with green amphibole (sp. 22-360); its exact relations could not be made out. It, or a similar bed, is found to the N.W. of the granite in the same relative position. Here the amphibole and mica are in separate bands, not intermixed. Another similar marble is south of Dadikar village, but the rock is slightly impure and has grains of magnetite and amphibole scattered through it (sp. 22-308, sl. 6848). East of Dadikar, in the next valley, is a broad and continuous band of dark green schist consisting of hornblende, quartz and plagioclase. Whether this is a sill or an altered effusive could not be determined, so much is the outcrop covered by detritus.

My reasons for considering this granite to be an intrusion and not of pre-Delhi age are—

- (1) the special physical disturbance and thermal metamorphism which the adjoining rocks have undergone,
- (2) the local production of certain minerals in these rocks—sillimanite, amphibole, sphene and mica,
- (3) the schistose condition of the selvedge of the granite,
- (4) the absence of any sign of conglomerate or grit at the contact with the quartzites, and
- (5) the occurrence (N. of Dadikar) of a tongue of quartzite projecting into the granite. This quartzite is vitreous and meets the granite with a sharp junction.

To the S.E. of this anticline, separated from it by a narrow isoclinal syncline in which a limestone (the Kushalgarh limestone?) is poorly

Alwar Fort.

exposed, is the smaller anticline crowned by the Alwar Fort. It is less dissected by strike-valleys than those hitherto described and has more the character of an irregular oval plateau bounded by an outward dipping wall of rock, the uppermost beds seen.

Eight miles due east of Alwar City, across the alluvial plains, is a small flat hill at the N. end of which is the village of Saroli. The rocks dip quaquaversally at comparatively low angles (10° — 15°) and though unmistakable Alwars, are more like sandstones than is usual. The nearest exposures, Ajabgarhs and breccia, form an incomplete circle round it and have a general dip away from the centre.

S.W. of the Alwar Fort anticline, another small oval anticline is seen between the two valleys, *i.e.*, synclines, which run northward from the plains and unite to form the Delawas valley, one of which contains the Siliser Lake and the other carries a small tributary of the Ruparel. A fault crosses this dome and passes north of the lake.

W. of the Delawa valley, between it and the sandy plains around the Sabi river, is a tangled wilderness of quartzite hills where the dip, so far as made out, is steadily to the west. This may represent a single isoclinal anticline, or several isoclines, inverted over the younger Ajabgarhs of the Delawas valley and occupying its normal position with regard to those of the Kushalgarh valley. Such parallel anticlines are shown in the projecting continuation of the mass to the N.W., where, S. of Rampura, is an oval anticline with almost vertical flanks. In contact to the W. is a second, more elongated and laterally compressed, the axial plane of which dips to the west.

Exposed at intervals round the Rampura anticline is an arkose quartzite much injected with trap. This appears as streaks and lenticular blebs of hornblende (with sphene, etc.) along the bedding, and is remarkably regular in its horizon.

At Kushalgarh village the Seriska and Bairas synclinal valleys join, bounding, with the northern continuation of the Ajabgarh valley, an irregular domed anticline of quartzites.

South of the Kushalgarh valley, which carries the Ruparel river, and which passes right across the hills from W. to E., the character of the Alwars begins to change. Dips are lower (15° — 20°) and instead of the scenery of narrow ridge alternating

with deep valley which has persisted so far, we find a tendency to the formation of bold scarps backed by moderately inclined dip-slopes. These are well seen in the Siliberi Kho and its vicinity, but the outer (youngest) ridge still presents a precipitous dip-slope to the eastern plains.

The general strike is roughly in the form of three sides of a square, the beds dipping outwards to west, north and east.

Along with this change in inclination, the texture of the rocks becomes more gritty and less coherent (sp. 22-341, sl. 6870) and felspar takes a prominent place as a constituent mineral.

A very coarse conglomerate, about 100 feet thick, occurs to the N.E. of the Siliberi Kho, striking N.-S.; it contains rounded boulders of pink and white quartzite as large as a man's head, in a matrix usually of quartz but sometimes of red and white mica-schist with small octahedra of magnetite. Towards its top it resembles a volcanic agglomerate of subangular quartz fragments in a base of dusty hematite and finer quartz (sp. 22-342, sl. 6877).

Siliberi Kho.

The Siliberi Kho presents some puzzling features.

The trap band on the northern side of the valley, below the conglomerate, is remarkably regular; the junction of the two is completely covered by scree-material. No pebbles of trap were seen in the visible portion of the conglomerate, the pebbles of which are quite similar to the quartzites below the trap, though not sufficiently distinctive for one to say that they have been derived from them.

The trap contains a quantity of biotite, which might be explained by its being a highly metamorphosed argillaceous tuff, but there are no signs of stratification. The presence of a thick conglomerate in conjunction with an amphibolite which is so regular as to represent perhaps an effusive lava or even tuff, signifies shallow water conditions and raises the possibility of a break in the succession, and the fact that above this no more igneous rocks are seen in the section tends to support this. The unconformity, if present, must be slight, since the dips of the beds above and below seem to be identical, and no evidences of overlap were obtained. In such comparatively highly inclined strata of very uniform character, an unconformity of small angle (*i.e.*, between the stratification of the two groups involved) is very difficult to

detect, since such short distances along the dip of the beds are visible for comparison.

The next two trap beds which lie below this in the section, between Siliberi Kho and the Tehla valley, are also very regular and may likewise be contemporaneous flows.

This suggestion is not discordant with the hypabyssal nature of the traps near Tehla, for the latter may be the intrusive bodies corresponding to the three effusives above.

The valley of Kankwari, really a slight depression in an elevated plateau, is largely occupied by one or more masses of trap, the highly irregular outline of which is alone sufficient to prove them intrusives. Other evidence is not wanting.

About 300 yards N.W. of the fort, is an outcrop of siliceous limestone injected with trap. The matrix is dark green, either hornblende or actinolite, including angular limestone fragments with the matrix material running in fine lines along their lamination (sp. 23-88, sl. 7636).

Near this is a small patch of limestone banded with actinolite (sp. 23-89, sl. 7637). Under the microscope grains of actinolite are seen to be scattered through the limestone, but in certain zones, defined by fairly sharp margins, it is profusely commingled with calcite and quartz. In this, as in all cases where the junctions of amphibolite with limestone or quartzite were examined, there is no fine-grained selvage, the amphibole crystals, of the normal size, interlocking with the quartz or calcite grains of the sedimentary.

About a mile S.W. of Kankwari, dykes of trap are seen alternating with a micaceous quartzite in a very irregular fashion.

Here also the Alwars are gritty and conglomeratic. To E., N. and W. they dip under the Kushalgarh limestone of the Ajabgarh and Kushalgarh valleys.

Omitting for the present the Tehla valley, which lies to the south of the Kankwari and Siliberi Kho hill-mass, we find that at Dangarwara, on the east of these hills, the Alwars resume their north and south strike, and a dip-fault shifts them westwards about $1\frac{1}{2}$ miles.

From here their outcrops sweep south-west and sharply back to north-east, indicating a remarkable compressed synclinal fold which encloses the Deoti Lake.

Some thin bands of conglomerate were noticed among the grits, but they are on the whole remarkably homogeneous (Pl. 5, fig. 2).

The fault which brings the Aravallis against them near Rewasa (p. 17) appears to shift them northwards several miles to near Todi, and passes obliquely across the Deoti syncline. When picked up again at Todi they still retain their character of arkose grits, false-bedded, and resembling gneisses except for the smaller size of the blocks into which they weather.

Here they have a thick coarse conglomerate (sp. 22-349) at their base—the Raialos die out east of Todi—resting on pre-Delhi schists which strike almost perpendicularly to it.

From Todi the Alwars run, with several interruptions, in a north-easterly direction, dipping N.W. and N.N.W., as far as Gugrod, in masses of low bare hills, their structure of scarp and dip-slope masked by irregularities of denudation.

The other limb of the Baswa "bay" anticline strikes almost north and south, passing east of Rajgarh to the railway at Golana.

From Golana eastwards the basal beds are arkose grits with pebble-bands.

On this side of the anticline the dips are almost vertical and the rocks are much altered, the conglomerates and grits (sps. 22-346-7, sls. 6880-1) having their pebbles flattened and showing under the microscope almost the structure of granites, and the quartzites being vitreous and shattered by irregular jointing. Some bands of mica-schist occur and mica is often developed along the bedding planes of the conglomerates, but in spite of such considerable alteration, ripplemarking is occasionally found.

East of Golana, along the scarp of arkose grits with pebble-bands, there is a very great decrease in the breadth of the Alwar outcrops, which die down to narrow ridges exposing a thickness of about 500 feet of rock, with a local widening of the outcrop east of Tatra. These ridges form three anticlines with a general north-east strike, the linear outcrops running in a zigzag, converging to the north-east and passing outside this area to the south, where they connect with the Alwars of the Biana-Lalsot hills.

The Reni "bay" anticline is the most western of these

Reni "bay." and the one in which the ridge is most continuous; the others become more disconnected when followed eastwards till they disappear in the alluvial plains of Bharatpur.

About a mile north-east of Parla, where there is a breach in the scarp, the rocks immediately above the granite are red grits and quartzites (sp. 22-347, sl. 6881) banded with quartz conglomerate in the lowest fifty or sixty feet. The actual junction forms a small debris-filled trench (Pl. 1, fig. 1), probably owing to the granite having been weathered to a certain depth down from the old surface exposed at the period when the Alwars were being accumulated, but the rocks are well seen a foot or so on either side of its position.

Westward of the gap, towards Golana, the sedimentaries are much altered, the grits become like finely foliated gneisses and the conglomerates dark red massive quartzites in which the pebbles can still be distinguished as paler oval spaces. It would be difficult to recognise them as elastic rocks were they not traceable into evident grits and conglomerates.

Along the scarp from Lada to Tatra the junction is well exposed, usually in the upper third of the scarp. Resting immediately on the granite is a coarse arkose grit about 20 feet thick, succeeded by quartzites, grits and slaty beds; the quartzites show ripple-marking and the beds as a whole are not greatly altered. North-east of Tatra there is a sudden increase in the thickness of the grits visible and a decrease in the height to which the granite rises on the scarp, so that the unconformity is not so well seen.

From Tatra to Bahadarpur the granite is capped by coarse variable grits, containing in the lower 70—100 feet numerous bands mainly of rounded and sub-angular quartz pebbles two or three inches diameter. A coarse conglomerate, two feet thick, occurs locally immediately above the granite. Higher than the zone of pebble bands is a great thickness of homogeneous pink felspathic grits (sp. 22-345, sl. 6879) which thin out to the east. At the top of the section, near Jakra, are several hornblendic bands and a limestone which probably represents the Kushalgarh limestone, but appears to have intercalated in it quartzites similar to typical Alwars.

In the railway cutting at Bhuda, where the scarp has become narrow again, a good section is obtained of about 500 feet of vertical quartzites, dark grey, thin-bedded and ripple-marked, with much hæmatite along their joint-planes and with numerous interstratified bands of red slate. These quartzites are less pure and more banded with slate than the Alwars are as a rule.

In the syncline between this and the western limb of the next anticline lies the double hill range running north from Mandaor or Mandawar (Hindaun Road railway station), which Hacket places in his Mandan series,¹ suggesting that they are Ajabgarhs, of which I think there is no doubt.

Towards the Banganga River these two ridges of Alwars bounding the Mandaor syncline practically coalesce and run into the Biana-Lalsot hills.

The western ridge of the Ranijo "bay" or anticline is a succession of low, narrow hills interrupted every mile or so by spaces of alluvium. To the south it is formed of highly altered felspathic grits, grey or pink on fracture and appearing red in the mass from the hæmatite films in fissures traversing them. North of the railway they become typical thin-bedded Alwars, and this character persists along the eastern limb of this anticline and the succeeding ridge, the last exposure of rock till the Vindhya of Fatehpur-Sikri outcrop far to the east.

Returning to the Deoti Lake syncline, the dividing line between it and the Tehla valley is a high curving ridge of almost vertical quartzites, vitreous and much metamorphosed. There are bands in which white ovals show the pebbles of conglomerates, now distinguishable from the matrix only by their difference in colour.

The Tehla valley is of triangular outline, bounded on all three sides by high scarps of quartzite, and is in fact an anticline. It drains to the south through a narrow opening at the apex of the triangle. The floor of the valley is diversified by a great number of trap hills and ridges of arkose grits, striking N.W. or W. with, south of Tehla, large expanses of the Raialo limestone.

Immediately above the limestone is a thick and striking quartzite bed. Its chief features are the fineness of its grain and the absence of distinct bedding. It dips at a high angle, and this, combined with its vitreous texture and lack of joints and stratification, causes it to form a serrated ridge with a scree in which the fallen blocks are of exceptional size. (Pl. 2, fig. 1.)

Wherever the Raialo limestone occurs, this quartzite is with it, but it thins out to the south and is overstepped by the higher

¹ *Rec., Geol. Surv. India*, X, pt. 2, p. 89.

quartzites. Along a section N.E. from Kho, the quartzite is repeated four times by faulting.

In the southern part of the valley folding has been more intense than towards the north, where lower dips and less indurated strata indicate that compression has been less. A number of faults, probably of the nature of lateral "tears," have permitted blocks of the Raialos and the basal Alwars to shift bodily northwards (as in the section N.E. from Kho cited above) from the more compressed area.

S.W. of Kho the "serrate" quartzite appears as the ridge which separates the Tehla valley from the Baldeogarh "bay",—a ridge which is structurally a syncline with the underlying Raialo limestone outcropping on either flank; a mile to the S.E. of Kho, at Daribo, this syncline becomes double, and in the intermediate anticline are situated the copper mines of Daribo, excavated in a local bed of slate between the "serrate" quartzite and the Raialo limestone.

Following above the quartzite, in the northern part of the valley, is a very thick amphibolite band
 Amphibolites and shown in groups of small hills, and faulted
 grits. along with the quartzite. Its outcrop
 is in places nearly a mile across (sp. 23-84, sl. 7632). Above this horizon the succession is very imperfectly seen. Micaceous arkose grits alternate with trap beds, but junction sections are few and give no definite clues to the mutual relations of the rocks.

There are at least eleven trap (amphibolite) bands in all, of varying thicknesses. Hacket enumerates ten bands and he also mentions hornblende rock *in addition to* trap, though without stating the distinction.

As the mineral constitution of all the bands is essentially the same, a separation is not valid, and I refer to them all as amphibolite or "trap."

The grits (sp. 23-67, sl. 7616) are coarse, dark-coloured, micaceous, fairly well bedded and lie at comparatively low angles, 15° — 30° . Under the microscope they are seen to consist of quartz, microcline, acid plagioclase and biotite, clearly the detritus of granites. They weather like the grits near Tatra, into smooth rounded bosses and bare sloping surfaces like those assumed by granite under insolation. Conglomerate layers and beds of finer schistose material are common.

In one case a slight unconformity without difference of dip was indicated by fragments of a distinctively banded slate occurring in a conglomerate a little distance vertically above the parent bed (sp. 23-66, sl. 7615).

The grits and conglomerates never contain fragments of amphibolite, which would be expected if the latter had been contemporaneous lavas subjected to denudation, a point tending to support my opinion that they are intrusive sills.

To the N.W. and S.E. the outcrops of the grits bend sharply round to the south and at the same time the beds become more steeply inclined and more altered. Their outcrops are markedly lessened in width, from the absence of what is in the aggregate the very considerable thickness of the included traps, as well as from the general thinning out towards the south which affects all the formations, and the apparent decrease due to the effect of steepening dips on the outcrop.

The trap bands die out somewhat suddenly in the compressed synclines to east and west of the valley, and there also the topography changes from the lines and groups of low hills in the Tehla valley to the bold ridges so characteristic of Alwar scenery.

The reason for the unusually open nature of the valley is that the grits, here less indurated than is normal, and weakened by faulting and by alternation with easily disintegrated traps, have given free play to denudation.

It would appear probable that the traps had been injected during folding, after the general trend of the axes had been determined, for where compression has been most intense, on the steeply inclined limbs of anticlines, traps are absent, while on the crests they have been enabled to force a way along the path of less resistance. These are the "phacolites" of Harker.² This arrangement of lenticular trap masses along the anticlinal crests is also seen near Kankwari and Kaler. The evidence of the intrusive nature of the trap has been gathered mainly elsewhere, but here were seen two somewhat inconclusive instances of trap penetrating quartzite and Raialo limestone.

Passing to the Baldeogarh "bay," there is in it little of interest except a band of coarse conglomerate above Baldeogarh "bay." the "serrate" quartzite, traceable west-

¹ *Rec., Geol. Surv. India*, X, pt. 2, p. 89.

² *Natural History of Igneous Rocks*, p. 77.

wards from the hot springs of "Naraini," $2\frac{1}{2}$ miles W.N.W. of Baldeogarh. This is probably the spring mentioned by Macpherson,¹ as in the Alwar country "20 miles north-east of Jeypore." "Naraini" is about 35 miles E.N.E. of Jaipur, but there must be some mistake in the distance which Macpherson gives, as no part of Alwar territory is within 25 miles of Jaipur town.

Where first seen the conglomerate is about 10 feet thick, composed of pebbles of clear quartz, pink felspar and dark grey, black, or dark red quartzite in a quartzitic matrix, in which are numerous grains of detrital tourmaline (sps. 23-71-2, sls. 7620-1). Followed south-west it becomes thicker and rises on the scarp, forming a prominent blue-grey cliff. Below it are soft, coarse sandstones and lower still an arkose conglomerate largely composed of balls of an orthoclase-tourmaline pegmatite or coarse granite, rather like the pegmatite in the pre-Delhi granite at Lada, but not resembling the granite near at hand. The conglomerate is above the horizon of the "serrate" quartzite, here absent or concealed except at the mouth of the valley east of Burjo, formed by a sharp fold in which the conglomerates are involved, where there are two small hills composed of the quartzite.

South of this the conglomerates seem to die out; they are quite local, but the general facies of the Alwar

Local unconformity. Series in the south denotes shallow water accumulation, and they may perhaps indicate a slight local unconformity or pause in deposition, like that which I have suggested may be present to the north of the Siliberi Kho, and several of which are known in the Biana hills,² where they are more easily recognized, as the Alwars are there moderately inclined.

As in his second paper³ Hacket includes the Raialos with the Aravallis, it is perhaps not irrelevant to point out that this possible pause in deposition is a very different thing from the great erosion unconformity between the Raialos (or the Alwars where the Raialos are absent) and the Aravallis, which is well seen about a mile to the south. The exact way in which the Raialos (including the "serrate" quartzite, which is below these local conglomerates and just above the Raialo limestone) follow the intricate flexures of the Alwars, makes it improbable that any deformation and

¹ *Ind. Annals of Medical Science*, Vol. III, 1854.

T. Oldham, *Mem., Geol. Surv. India*, XIX, pt. 2, p. 35.

² *Rec., Geol. Surv. India*, X, pt. 2, p. 87.

³ *Rec., Geol. Surv. India*, XIV, pt. 4, p. 281.

denudation of the Raialos preceded the deposition of the Alwars. It merely indicates that minor oscillations of level *may* have taken place on this horizon and that of the Siliberi Kho conglomerate, without any axial uplift. The straight and narrow gorge in which the Ajabgarh stream flows past Burjo is one of the unusual cases in which a striking feature of the configuration is not intimately related to the geological folding. It is a plagioclinal valley, crossing the strike at a low angle. Its straightness, and the abrupt diminution in the thickness of the Raialos at its end, near Bhangarh, leads me to suspect that it may owe its trend to its having been cut out along a line of faulting.

The "bay" in which Jhiri, Kaler and Raialo are situated bears a general resemblance to the Tehla valley, but Raialo "bay." here faulting and folding have produced an even more complicated structure.

Above the Raialo limestone the succession is the same, a fine-grained, vitreous quartzite, a thick trap and a series of thinner sills and grit beds, than the main mass of the Alwar quartzites.

The sills keep to their respective horizons with great regularity, though when their boundaries are mapped they prove to be markedly lenticular.

Traps.

In several places patches of trap a few inches across were seen in section, surrounded on all sides by the sedimentaries through which they had made their way. Though such were comparatively scarce taking into consideration the large area examined, even one or two such occurrences are enough, in the absence of contrary evidence, to prove the case for intrusion.

On the west side of the Raialo "bay," the quartzite above the Raialo limestone and the thick trap sill which overlies the quartzite are well exposed, but as they are followed southwards they thin out and disappear *pari passu* with the Raialos.

North of (i.e., above) the thick trap are three thin but very regular traps divided by narrow bands of quartzitic grit, and then another very large lenticular trap, probably on about the same horizon as those in the hills a mile N.E. of Kaler, and N.W. of Semra. Its outcrop is over a mile wide; angles of dip however being unobtainable, its real thickness can only be guessed at two or three thousand feet. It has forced its way into the upper Alwars enclosing the south end of the Partabgarh syncline, and approaches the Ajabgarhs.

N.E. of Raialo the trap above the "serrate" quartzite is crossed by a fault, oblique to the strike, which becomes a dip-fault near Kaler and is joined by another dip-fault passing $\frac{1}{2}$ mile W. of Raialo and shifting the Raialo scarp northwards over a mile. Along the line of this latter fault the trap veins in the pre-Delhi granite are sheared and schistose, and a small exposure of the Raialo quartzite seems to have been dragged along the line of the fault. The hill at Semra (Pl. 7, fig. 1) shows three separate trap bands and three grits, forming terraces and dipping north at 15° . The upper two are thickest, about 50 feet. To the west they swing up to verticality and are lost below alluvium, but reappear a little to the south, roughly parallel and dipping in the same direction. As far as can be ascertained from the imperfect evidence available, this is probably a centroclinal trough which has been compressed in a N. and S. direction into an isocline.

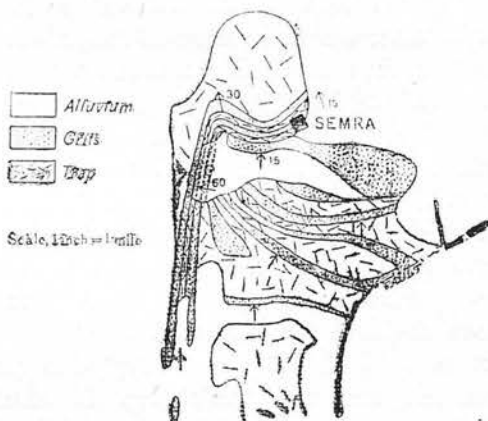


FIG. 3.—Diagram of Semra isocline.

The faults shown on the map can as a rule be traced only by the shifting of outcrops which they cause; infrequently other signs are seen—small exposures of breccia, quartz veins, and in a single stream section, actual fracturing of the strata.

The high scarps bounding the "bay" to east and west are largely conglomeratic and gritty quartzites. At its northern termination near Partabgarh a change sets in, the quartzites become finer grained and mica-schists appear in noticeable amount.

Adjoining to the west is the synclinal valley of Partabgarh in which the Ajabgarhs have been preserved, with another anticline to the west of it.

Partabgarh.

N.W. of Partabgarh, on the Jaipur frontier, an anticline of Alwars is beautifully shown by the topography of the map, harder strata forming an almost unbroken wall surrounding an oval space occupied by alluvium and softer rocks. The eastern side is vertical or inverted, the western dips steeply outwards. A line drawn E. and W., a little to the north of Partabgarh, would cut three anticlines from the above to the great syncline of the Ajabgarh valley proper. They are all inverted in the usual way, approximately isoclinal the axial planes of which dip westward. They die out *en echelon* from the east, one after the other pitching under the newer rocks; the most westerly may perhaps extend to the north of the Bairat granite but the disturbed state of the strata makes this uncertain. Throughout the entire length of the Ajabgarh valley, from Ajabgarh in the south to where it opens out on the plains, the Alwars are, on the west, inverted over the Kushalgarh limestone and younger rocks. On the other (east) side of the valley the superposition is the normal one.

N.E. of Partabgarh there are several trap bands, regular but thin and poorly exposed; near the Bairat and

Bairat traps.

Basi granite intrusions they become more numerous. On the east of the Basi granite the schists are copiously streaked with amphibolitic bands running mainly along the strike but discontinuous within short distances. They contain garnets, perhaps caught up from the schists, which are rich in them.

From the northern point of the intrusion a conglomerate (sp. 23-93, sl. 7641) runs along the Jaipur side of the State boundary; the matrix is micaceous grit but has been so profusely injected with amphibolite that in places it is unrecognisable. In microscope sections the hornblende is seen to be in lines, knots and isolated crystals in the mosaic of crystalline quartz, as if it had been forced in along planes or lines of weakness.

Two miles E. of Bairat is a large triangular mass of heavy, black, slightly schistose rock, the most basic amphibolite encountered, showing in micro-section dark areas of strongly coloured green hornblende, apatite and sphene, and paler areas of enstatite, diopside and hornblende (sp. 23-95, sl. 7643). No quartz or fels-

par is present. I have elsewhere remarked (pp. 92, 95) that amphibolite dykes are absent from the Bairat and other granites and that this corroborates other indications that the granites are subsequent to the amphibolites. It is not unlikely that the profusion of traps in the neighbourhood of the granite masses may be due to both having taken advantage of the same local weakness for their ascension; the traps at least seem to favour assemblages of micaceous or gritty rock rather than the compacter quartzites.

N. of Bairat, in the large mass of hills between Malothano and Badgaon, the Alwar quartzites are not typical. Hills N. of Bairat. They are somewhat felspathic, and dark grey or brown in hue (sp. 23-73, sl. 7622). By reason of their impurity they are softer and weather with a rather thick crust, more after the manner of the quartzitic Ajabgarhs. Argillaceous zones also are of more frequent occurrence.

The upper beds, which in the S.E. part lie near to, and inverted over, the Kushalgarh limestone, swing sharply to the west through a right angle, striking against a double ridge which is faulted into a position inclined to them.

On the south-west side of the hills the folding is rather complex. An anticlinal axis runs north and south near Malothano, the strata on the east inverted, those on the west dipping at about 20° . Followed south the outcrops of the latter swing sharply round through a right angle, at the same time becoming vertical, then back again to their original N.E. or N. strike, and lastly another sharp bend brings them to an easterly strike, when they are cut off by a fault.

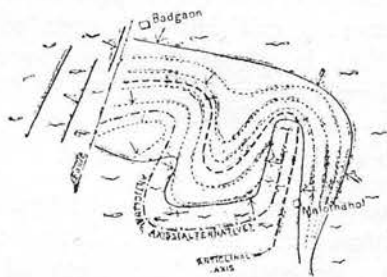


FIG. 4—Diagrammatic plan of quartzite outcrops between Malothano and Badgaon.

Another alternative explanation of the structure is given in the diagram.

In a detached hillock $\frac{1}{2}$ mile N.W. of Badgaon is a very clear case of intrusive amphibolite, a coarse actinolite rock along the bedding of a quartzite, but breaking across it and enclosing pieces torn off from the quartzite.

On the eastern side of the Ajabgarh valley the Alwars call for no remark, except that the top of the ridge that they form, overlooking Kankwari, is strikingly level. Looked at from the floor of the valley, the effect of mile after mile of rampart sloping steeply from crest to base, is most remarkable. This stretch is broken where the Ajabgarh valley opens out to that of Seriska and Kushalgarh through an opening where the Alwars dip under the newer rocks. South of this passage the Alwars hem in a very narrow synclinal branch of the Seriska valley running up to Kalighati Gwara and lying between the Kankwari plateau and the Siliberi Kho.

East of Kalighati Gwara dips are rather low, about 15° , bordering a plateau between the Siliberi Kho and Kushalgarh, a tract where the strata roll slightly, but are nearly horizontal.

CHAPTER VI.

KUSHALGARH LIMESTONE.

Between the Alwar Series and the Ajabgarh Series and passing conformably down and up respectively into them, through arenaceous and argillaceous transition beds, is the Kushalgarh limestone. Like the Raialo limestone and quartzite it is local, or at least is not present in the Torawati and Shekawati hills to the west of this area; elsewhere in Rajputana, Delhis higher than the Alwar Series have so far not been recognized.

Its relation to the hornstone breccia I shall treat of in detail in the following chapter. Except in the synclinal valleys where the Ajabgarhs are preserved by being folded into the *massif* of Alwar quartzites, the limestone is seen only in small and disconnected outcrops, and it is always difficult to investigate, occurring as it does on the plains or on the level bottoms of the valleys at the foot of great dip-slopes of Alwar quartzites, which cover it with their debris. Even when sufficiently far from the Alwars to obviate this, the exposures do not rise to any great height above the alluvium. Visible junctions with the rocks above and below are infrequent, and since there is a gradual passage up and down into the adjacent formations by insensible gradations, an exact determination of the thickness is impossible, but it is about 1,500 feet as a maximum.

It is usually conspicuously banded with layers of alternating dark grey and black, an inch or two broad, weathering unequally, probably in consequence of the variable proportion of quartz which they contain (Pl. 10, fig. 2). These are often somewhat waved along the strike. Besides calcite it usually contains a considerable amount of quartz and some mica and a dusty black substance, probably a form of carbon. It is not dolomitic (p. 27). Where it has been highly metamorphosed, as in the Delawas valley, it loses its banded structure, and amphibole is largely developed in long bladed crystals and in tufts of asbestiform needles.

The rock is practically unjointed and unstratified, except for the raised bandings above noticed, but it does not split appreciably

more readily along these than in other directions. Dip and strike coincide with those of the underlying Alwars which are found near the several exposures.

I shall describe the occurrences in the Kushalgarh, Ajabgarh and other synclinal valleys among the Alwars, and then a few of the more interesting of the disconnected outcrops on the plains.

In the Delawas valley west of Alwar, the limestone is repeated three times at the north end (head) of the valley, outcropping at both sides of the main valley and also in an anticlinal roll between two outliers of Ajabgarhs which form subsidiary synclines. In the medial portion of the valley the fold is single, so the limestone appears only twice, but to the south, near the Siliser Lake it occurs four times in small exposures, as the syncline is here again doubled, the axis of the intervening anticline pitching high enough for an oval of Alwars to be exposed between.

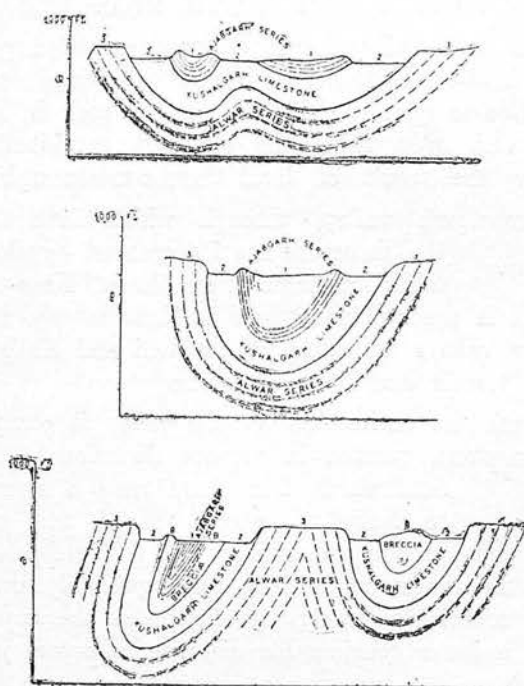


FIG. 5.—Sections through head, middle and foot of Delawas valley. Scale 1 inch to 1 mile.

At the lower end of the valley the rock has its normal regularly banded character, but followed northwards, where metamorphism has for some reason been locally more active, it would be unrecognizable as the same but for the field evidence of identity. About Delawas it becomes a coarsely crystalline marble (sp. 22-315-6, sl. 6855) full of large bladed crystals of grey tremolite, which remain when the calcite has been dissolved away, leaving a thick cellular weathered crust of felted tremolite rods. There is much injection of white quartz in small veins and stringers.

Both here and two miles due north of Delawas, $\frac{3}{4}$ miles north-north-west of Rosra, on the eastern side of the valley, the bladed tremolite is locally modified into radiating groups of asbestos needles, occurring at random through the rock in masses of indefinite size and shape. (Sp. 22-317, sl. 6856, sp. 22-319, sl. 6858.) This, the more refractory but less flexible and weaker variety of asbestos, is usually found in greater proportion to the country rock than the chrysotile variety, but its economic value is much lower.¹

At the head of the valley the limestone is mottled pink (calcite) and green (actinolite), a rather handsome rock, and contains some sphene in addition to quartz. The bulk of the rock is, however, the normal black and grey type, the coloured amphibolitic varieties being probably the result of local thermo-metamorphism.

In the Kushalgarh valley, through which flows the Ruparel, the limestone has its greatest development and takes its name from here. Near Kushalgarh, where limestone is predominant, there is little breccia; *vice versa* in the tributary valleys extending up to Rehi and Kalighati Gwara, there is much breccia and little limestone.

At Kushalgarh the entire floor of the valley is occupied by the outcropping limestone, twisted in various directions (Pl. 10, fig. 2).

Kalighati Gwara. Southwards from here runs a synclinal valley to Kalighati Gwara, broad and open at its commencement but rapidly narrowing by the steepening of the dips. In this the limestone is little seen, probably owing to the fact that the breccia is largely developed (at the expense of the limestone) and is for a considerable distance in actual juxtaposition with the Always.

¹ Bull. Imp. Institute, Vol. III, p. 277.
Cirkel, "Asbestos" Canada Mines Dept.

On the central plateau of quartzites east of this, at Lilola, there is a shallow depression containing an outlier of Kushalgarh limestone isolated from the main valley by quartzites. On the east side the dip is low, decreasing to horizontality at the centre. The west side is either a fault of small throw or a sharp monoclinal fold.

In the Bairas valley, which runs north from Kushalgarh and opens into the Ajabgarh valley near the mouth of the latter, the limestone is exposed continuously round the margins, between the dip slopes of Alwars and the uneven ground of Ajabgarhs occupying the centre of the valley.

On the south side of the Kushalgarh valley near Seriska, and continued thence into the main Ajabgarh valley, following its east side for about nine miles, the Kushalgarh limestone outcrops in a longitudinal depression between the Alwar quartzites on one hand and, on the other, hills of siliceous and argillaceous limestone belonging to the Ajabgarhs. It is banded as usual, but the paler bands are often pink and crystalline, due doubtless to their being less impure than the normal.

In the southern part of the Ajabgarh valley the limestone is a good deal contorted and brecciated, and where its top is seen it has ferruginous bands instead of siliceous. This variety, when smashed up, would evidently form a ferruginous breccia, and such a transition is actually seen. Most of the breccia here is from a pink or purplish quartzite locally intervening between the limestone and the Ajabgarhs. At the apex of the valley argillaceous material is so abundant that the rock can hardly be called a limestone.

On the west of the Ajabgarh valley, exposures of the limestone are few and far between, partly owing to the Alwars being inverted over the limestone, thus burying the outcrops on the low ground even more than usual, partly owing to the large development of hornstone breccia and the usual concurrent decrease in the limestone. Where it passes down at its base into the Alwars, micaceous and flaggy beds are usually seen.

In the small outcrops near Badgaon tremolite is present to some extent, a mineral from which the Kushalgarh limestone is free in the Kushalgarh and Ajabgarh valleys, contrasting with its abundance in the Ajabgarh limestones higher in the sequence and nearer the centre of the syncline.

One and a quarter miles west of Badgaon is a small knoll of a beautiful black and white banded marble, doubtfully Kushalgarh, which would make a very ornamental building-stone (sp. 23-65, sl. 7614).

A belt of typical Kushalgarh limestone is seen running north from a point 1 mile due west of Ajabgarh, West of Ajabgarh valley, apparently (the structure here is very difficult to unravel) caught up in a subsidiary and narrow isocline. Almost against it is faulted the thick amphibolite band above the "serrate" quartzite (p. 47), and only a mile away is the Raialo marble, rendering prominent the marked dissimilarity of the two calcareous types.

In the Partabgarh valley the limestone has become much thinner but still retains its typical characters; outside the present area to the west and south it seems to be quite absent.

Taking up now some of the more or less isolated outcrops on the plains, the first case is far to the north, Barod, near Barod, where gently dipping beds of crystalline limestone with breccia above, are exposed in the centre of an almost vertical anticline of the Ajabgarh (Mandan) Series (see p. 76).

Near Alwar City there are only two small exposures too small to show on the map, one 2 miles north Plains east of Alwar City, of Saroli, forming part of the incomplete ring of younger rocks round the dome of Alwar quartzites (p. 42), the other, a very small one, 4 miles south of the city. They are both normal and underlie the hornstone breccia.

At Akbarpur, besides several unimportant outcrops to the north-east, the limestone forms a prominent hill overlooking the town and dips below the breccia, the junction being well seen. Low in the section the bands are quite even, but higher up, near the breccia, they are twisted.

From Akbarpur southwards for about 13 miles there is no outcrop of limestone, and the breccia when seen is very thin; unless the former has been cut out by strike faulting (of which there is no direct evidence) it has here not been deposited.

At the north end of the compressed syncline of the Deoti Lake the limestone is seen only on the east side Deoti Lake, where it cuts across the breccia, here in great

force, and is full of injected quartz, and is crystalline. In the south it outcrops on both sides of the valley and round its end. It is thick but more argillaceous than normally, in fact it seems in places to change along the strike partially into shales, which may or may not weather in a fashion similar to the limestone.

The major part of the exposure 1 mile north-east of Begota is altered to a pale grey marble, tremolitic or free from tremolite; when the latter it is pink or cream-coloured, and being hard and fine grained, is an excellent ornamental building-stone; it is in considerable quantity and lies near a railway (sp. 22-328, sl. 6867). An exposure of white Raialo marble at Todi near here also deserves attention economically (sp. 22-325, sl. 6864).

West and north of Gugrod, between the Alwar quartzites and the long loop of Ajabgarhs forming the outer limit of the anticline, are five small outcrops of limestone, not shown on the map, preserved from removal by the resistant breccia, at the foot of hills of which they lie. In the most easterly, north-east of Gugrod, an impure contorted amphibolitic limestone (sp. 22-320, sl. 6859) passes down through a dark brown ferruginous limestone into black slates and fine quartzites. The breccia truncates abruptly both slates and limestone.

The next to the west is of breccia, with a band of hard grey limestone, somewhat smashed, on its southern side, *i.e.*, lower in the section.

In the next hill, north-west of Gugrod, the breccia is south of, *i.e.*, below, the limestone, which is like the last-mentioned, and is much shattered and injected with white quartz (Pl. 11, fig. 1).

The limestone (sp. 22-322, sl. 6861) in the fourth is the same in structure and position; in the most westerly outcrop of the five, however, the relative position of limestone and breccia is reversed and the limestone is pale and free from quartz-veining.

Farther north in the same anticlinal loop, at Gotri, the top of a whitish limestone overlaid by slates, is seen. It is in low folds and comes to the surface in several places, but little of it is ever exposed; it may be the Kushalgarh limestone or only a calcareous band in the Ajabgarhs. It occurs in similar fashion in the parallel anticline to the south-east.

The remaining cases, above the basal Alwars of the Reni "bay," are doubtful and unimportant. There is a greater development of slates near its horizon, probably replacing the limestone in part,

which is just what would be expected to accord with the littoral character of the other sediments in the south. (Kushalgarh limestone—sps. 22-315-9, sls. 6855-8, sps. 22-321-4, sls. 6860-3, sps. 22-326-8, sls. 6865-7.

CHAPTER VII.

THE HORNSTONE BRECCIA.

General Description.

This curious and interesting rock is merely mentioned by Hackett,¹ who states that it "is generally found on the top of the Kushalgarh limestone, but is frequently absent," and does not attempt an explanation of its origin. I shall describe generally its character, then refer to some of the chief occurrences and lastly suggest how it may have been formed. It outcrops in a similar manner to the Kushalgarh limestone, forming hillocks on the plains or among the scree material of the Alwars, often in contact with the limestone and protecting it from denudation, and it also is local and is not found outside this area.

As a rule it occurs above the Kushalgarh limestone, *i.e.*, at the base of the Ajabgarhs, but there are exceptions to this, in which it is found below the limestone, above the Alwars.

The breadth of its exposures, measured in a direction perpendicular to the strike of the adjacent bedded rocks, may be as much as half a mile, but as it varies indefinitely up to this limit and seems sometimes to be wanting entirely, and is besides an unbedded rock, an average thickness can hardly be stated.

The most usual variety consists of abundant, perfectly angular fragments of pale grey and dark grey quartzite, of all sizes up to that of a man's head, imbedded in a matrix which appears compact and cherty to the unaided eye but under the microscope is seen to be granular, with as a rule much interstitial limonite coating the grains. The quartzite fragments are identical in macroscopic and microscopic characters with types of the Alwar and Ajabgarh quartzites, and in addition pieces of slate similar to the Ajabgarh slates, but usually porcellanised, and pieces of white quartz, evidently brecciated vein-material, are present.

¹ *Rec., Geol. Surv. India*, X, pt 2, p. 88.

In the highly comminuted varieties of the rock different kinds of fragments may be found indiscriminately mixed in all proportions, but in less extreme cases of brecciation only one sort may occur, this showing what the original rock was. In such cases, as for example in the slates south of the Deoti Lake, the original structure of the rock has been partly preserved.

The matrix does not vary except in the amount of iron oxide which it contains, colouring it from pale yellow to a dark brown.

The more ferruginous varieties have been used as iron ores, and in one or two places, *e.g.*, Akbarpur, manganese ore secretions occur, but only in small quantity.

Where slate has been the parent rock of the breccia, the matrix is the same material comminuted and with a calcined look, due perhaps to the carbonaceous content having been consumed, either by heat developed through friction or by heated vapours ascending through the much fissured rock.

Where thoroughly brecciated it is quite devoid of any traces of regular jointing or stratification, but in places where the action has been less complete, as north of the Siliser Lake and south of the Deoti Lake, its more or less obscure bedding dips at much the same angles as the adjacent rocks, but is better seen from a distance than when examined in detail.

Save in cases where it is of a slaty nature, the breccia is a very hard and resistant rock, owing to the hardness of the quartzite fragments and the compact and siliceous matrix, which latter however weathers more easily, leaving the quartzite fragments standing in relief. (Pl. 9.) It gives rise to small steep conical or rounded hills, presenting rugged knobs of the breccia protruding from slopes of detached blocks and chips which have weathered out.

From its sharply angular nature this debris lies at a high angle of repose and remains on steep slopes, its accumulation tending still farther to obscure these disconnected outcrops nearly buried in alluvium and scree material. The determining factor in the colour is the ferruginous content of the matrix, so the prevailing hue of the rock, both in hand specimens and as a scenic feature, is brown varying from buff to almost black. (Hornstone breccia--sps. 22-295-305, sls. 6840-6, sps. 23-98-103, sls. 7646-8.)

Exposures in detail.

As the separate exposures are very numerous I describe only those which are in contact with other rocks or have some special feature of interest.

The hill at Kithur, 12 miles north-east of Alwar, is a clear case of brecciation *in situ*. On the north side the breccia is composed of undoubted Ajabgarhs—black glassy quartzites, rough grey sandstones of the Berla variety, and pieces of soft grey clay-rock and black slates, in a matrix rich in iron, and it has a crudely bedded appearance from a distance. Passing to the south, the rock is less and less smashed until almost unaffected beds are reached. Two miles north-east of this, at the end of a ridge projecting westwards, a similar mass is seen shading into unbroken Ajabgarhs.

On the plains east and south of Alwar City the first exposure is 2 miles north of Saroli, where the Kushalgarh limestone is seen dipping below the breccia. Towards its top the limestone becomes more siliceous and passes into a banded quartzite, which still higher is fractured and shattered, resulting, by the gradual increase of the fine-grained interstitial stuff and the introduction of limonite therein, in a mass of quartz fragments in a ferruginous matrix (sp. 22-296, sl. 6841).

At Akbarpur the breccia and the Kushalgarh limestone form a prominent hill, their mutual junction dividing it medially. Near the junction the bands in the limestone are twisted and it passes up into a fine, soft, greyish black siliceous rock, like the carbonaceous quartzite described below, in the Delawas valley (p. 68). On this the breccia lies quite evenly, its lowest portion being a white quartzite some inches thick. The only explanation I can suggest for the absence of disturbance at the junction is that the soft, graphitic rock has acted as a kind of lubricant or yieldage-plane permitting wholesale sliding to take place. At Ahmadpur, $\frac{1}{2}$ mile south-east of Akbarpur, a small band of black slate is seen bounded on both sides by the breccia, but the junctions are concealed by breccia debris. From the entrance to the Kushalgarh valley southwards to the beginning of the Deoti valley the breccia is almost, and the limestone quite, absent, so that the Ajabgarhs are nearer the Alwars than usual.

On the north-west side of the Deoti valley the breccia is still inconspicuous and runs through the Ajabgarh quartzites and slates, with an abrupt thickening at Kundla, where it is largely composed of white quartz, probably injected material. The large mass of breccia at the head (south-west end) of the valley is rather curious. Most of it is a pale grey, streaked quartzite, fine in grain, porcellanic and structureless, looking like shale which has been intensely baked.

It is shattered in the usual manner (sp. 22-305). The very ferruginous type is also present, partly composed of slate fragments and partly of comminuted white quartz, with the matrix showing mammillated and radiating structures, evidently the result of aqueous deposition after solution or infiltration. Its great thickness is probably due to the two sides of the syncline being here in contact. On the south-east side, from the head of the valley to north of the Deoti Lake, the breccia is poorly developed but was studied in considerable detail immediately south of the "bund" of the lake, where it affects the Ajabgarh slates. All intermediate gradations can be seen from crumpled slates to the normal type of a confused mass of slate fragments. (Pl. 10, fig. 1.)

Plate 8, fig. 2 shows a quartz vein in the slates, broken up, and the interspaces filled with the material of the slates.

North of the lake the breccia thickens and is faulted against the Alwars by the Rewasa fault (p. 45). This fault crosses the valley obliquely, bringing the Ajabgarhs against the breccia and the limestone. The latter is in its normal position at first but divides into two, one branch continuing along the usual horizon while the other passes transversely across the breccia, giving rise to an oblique valley, and then running parallel to and stratigraphically above it. The limestone itself is crystalline and much shattered and injected with quartz. The duplication of the limestone is probably due to thrust faulting, or to the "plane of brecciation" (p. 72) having divided into two.

The five small hills near Gugrod have been described in connection with the Kushalgarh limestone (p. 61). In some of them the breccia seems to be below the limestone, in others above, but unfortunately little could be learned from them, owing to their isolation from each other and the absence of visible junctions between the breccia and the other rocks. The relative difference of position may be due to shifting of the "plane of

brecciation " or may be merely a deceptive appearance, due to rolling folds, by which the breccia and the limestone seem to interchange their positions when seen only in disconnected outcrops.

In these occurrences the matrix of the breccia is rather scanty and the rock is more slaty than usual, though the much smashed type is also found. Inclusions of non-brecciated masses of slate and of fine black quartzite are numerous, and it is sometimes difficult to decide whether a given exposure should be mapped as slate or breccia. The broken and quartz-injected state of the limestone about here has been mentioned (p. 61).

Curving round the Alwar grits near Jakra at the head of the Reni " bay," the breccia is present on two horizons.

Jakra.

One and half miles north and north-east of Jakra it lies *above* some (Ajabgarh) slates and its junction with them is visible. Towards their top the slates become more siliceous, less laminated, and copiously and irregularly iron-stained and jointed, but sparsely injected with vein-quartz. They are indistinctly banded with grey. Quite abruptly they give place upwards in the section to a yellowish-brown rock, almost a sandstone, full of fine quartz veins which have been shattered and jumbled. Within a few feet higher this becomes a breccia of pure white and yellowish-brown quartz in the usual matrix, but it retains a rude banding, waved in places, and large unbroken blocks of quartzite several feet across are seen in it.

Half a mile from these slates, running parallel with them lower in the section, is a limestone band with breccia above it. As the breccia is in turn topped by a thick bed of what has every appearance of being Alwar quartzite, the correlation of this limestone as Kushalgarh is doubtful, but we evidently have here two planes of brecciation a considerable distance apart, both occurring in or near soft rocks (slates and limestones) and having between them a hard stratum which is unaffected.

In the synclinal valleys among the Alwars the breccia is more Siliser Lake. continuously exposed than on the plains.

North of the Siliser Lake near Alwar City it lies in a syncline of the limestone, the normal black banded type, becoming upwards pale brown and massive and passing into a banded quartzite with its layers twisted and broken, and ultimately has the normal appearance of the breccia but with a pale matrix (sp. 22-298, sl. 6842). Near the top of the hill it is more ferruginous. In the

larger outcrop north of the lake, the breccia has more resemblance to the Ajabgarh quartzites and from a distance looks distinctly stratified. Above the limestone are a thin red and white banded sandstone and a black, fine-grained, shale-like quartzite (sp. 22-280, sl. 6830), cracked and seamed with small veins of white quartz, but not brecciated.

In the north of the Delawas valley the breccia must be absent, for if it were present it could not be missed
 Delawas valley. in the sections seen near the head of the

valley.

About a mile south of Delawas the above black, quartz-veined quartzite occurs and probably represents the breccia. The black colour is due to graphitic matter, and the white veins, coarsely crystalline under the microscope, are quartz either deposited from aqueous solution or injected.

At the entrance to the Kushalgarh valley the scattered hillocks around Baori are partly normal highly ferruginous breccia, others show quite clearly, by sparingly shattered areas in them, that they have once been the Ajabgarh quartzites and slates.
 Kushalgarh valley.

The long hill 1 mile east-south-east of Kushalgarh shows this well, its north-west end being almost undoubted Ajabgarh quartzites passing along the strike into very ferruginous breccia. On its southern side are the ruins of furnaces, and along its top a line of small deep pits, said to have been sunk for copper. Not a trace of copper mineral could be found, but iron-ore is plentiful, though poor in quality. Below the eastern end of this ridge, in the bed of the Ruparel, is one of the very few cases seen of brecciated limestone (sp. 22-300, sl. 6843), composed of sub-angular pieces of siliceous limestone set in a darker matrix of the same substance.

As above mentioned, in the description of the Kushalgarh limestone (p. 58), the breccia is in great force in the Kalighati valley forming high ridges, on the east close to the Alwars, on the west the limestone intervening between them.

The small hillocks north of Seriska, below the Alwar dip-slope, are slates and breccia more or less merging into each other.

North-west of Seriska, the *Alwars* are smashed up in an extraordinary fashion, giving rise to a rock similar to the breccia, but carrying no ferruginous material in the matrix—in *situ* brecciation has taken place without the introduction of foreign material.

In the Bairas valley the breccia is absent, as at the head of the Delawas valley, but is represented by a massive, unbedded, tremolite-bearing limestone, much veined with white quartz.

This type of rock is frequently seen in the Ajabgarh valley, and it is evident that when more copiously shattered and quartz-injected, and with part of its calcite replaced by silica, an interchange which is facilitated by such disruption, it would be identical with some varieties of the breccia. All gradations between the two have been seen.

In the main Ajabgarh valley south of Todi-Judawas the breccia divides into several narrow, roughly parallel belts, one of which crosses the strike at an angle. Most of this is in the usual impure and sparingly jointed Ajabgarh quartzites, but at Kishori a band of slates forms a low ridge and displays copious shattering but without any appreciable ferruginous quartz-veining. (Sp. 23·100.)

It is probable that the apparent scarcity of breccia composed of slate or limestone is due not to a real paucity of such a rock, but merely to a deficiency in outcrops, from the ease with which it is denuded as compared with the more quartzitic forms. The matrix in nearly all cases is siliceous, with a varying amount of ferruginous material, and it is evident that quartz fragments imbedded in quartz form a more homogeneous and therefore more resistant mass than limestone or slate, also in a quartz matrix.

The group of slate hills north of Ajabgarh has several bands of brecciation, mainly of the dark, highly ferruginous kind.

Along the west of the valley breccia is in force, at least much of the area consists of smooth hillocks covered with quartz fragments, which may have arisen from the disintegration of quartz-veined slates or limestone, or from the true breccia.

At Suratgarh it takes a sharp 'S' bend following the line of the Alwars; the Kushalgarh limestone dips below it; above it are black slates and argillaceous (tremolitic) limestones, brecciated in places, belonging to the Ajabgarhs. From Suratgarh the line of quartz-strewn hillocks is fairly continuous to about 2 miles south of Basi, where a rude stratification is clearly visible in the breccia, shattered layers of black and white, as if the slates making up the breccia had been partially heated and drawn out along the bedding. About here there is a large spread of quartz-injected and tremolitic Ajabgarh limestone like that of the Bairas valley (p. 69), lying at low

¹ *Rec., Geol. Surv. India, XIII, pt. 4, p. 244.*

angles and dipping in some cases below normal breccia, in others below mounds of quartz and quartzite fragments.

Four miles south of Basi there is an abrupt right-angled bend in the Alwar scarp, where the quartzites are comminuted like those seen near Seriska (p. 68), with a scanty matrix devoid of introduced material. This passes sharply into the unbroken quartzites, here vitreous and abnormally thin-bedded.

In the small syncline south of Partabgarh the breccia does not form separate outcrops, but is found, greatly diminished in thickness, in brown quartzites and slates just above the limestone. Though thin it is fairly continuous and keeps to a definite horizon at the base of the Ajabgarhs.

Though by no means an exhaustive description of the breccia outcrops, the above includes all that are instructive or important.

The Origin of the Hornstone Breccia.

The supposition that the rock is an ordinary epiclastic breccia, arising from the subaerial disintegration of older strata, is untenable, for the similarity which it often has to both underlying and overlying rocks, its occasional bifurcations and the inclusion in it of unbrecciated strata and bands of slate, the varying amount of smashing displayed, its usual gradation up and down into the adjacent beds, and the parallelism in dip of the beds above and below it, all point to its being autoclastic.

The fact that it occurs, in many instances though not always, above a thick limestone, suggested that it might have been created by the settling down of the beds above the limestone by the diminution in volume of the latter on the (hypothetical) solution and removal of part of its calcite content, a way in which the Tirohan (Lower Vindhyan) breccia of Bundelkhand¹ and Karauli² and the South Mahratta country³ breccias were probably formed, but I am unable to bring forward any particular evidence in the present instance. Besides the limestone is sometimes *above* the breccia, so collapse on solution cannot be the main cause, though perhaps it is a subsidiary one.

¹ Medlicott, *Mem., Geol. Surv. India*, II, p. 13.

² Mallet, *Mem., Geol. Surv. India*, VII, p. 60. Hacket, *Rec., Geol. Surv. India*, XIV, pt. 4, p. 288.

³ Foote, *Mem., Geol. Surv. India*, XII, pt. 1, p. 76.

That it is the breccia of a normal fault may be at once ruled out, from the very sinuous trend of its outcrops (though approximately parallel with the constantly varying strike of the rocks at hand), its occasionally visible bedding and its great breadth of outcrop.

Let us consider, however, the effect of great compressive stresses on such a sequence of strata as is here present, but before actual buckling takes place.

Compression of heterogeneous strata.

We have at the base the Alwar quartzites, thick, hard and homogeneous, with a limestone which is also homogeneous. Above this is a band of slates and then follows a set of beds, the quartzites in the Ajabgarhs, whose pre-eminent and distinguishing character is the alternation of hard and soft rock.

On the first application of the tangential compressive stress involved in the formation of a range of folded mountains, one would expect that these upper beds (Ajabgarh quartzites) might yield and wrinkle in the manner of a tablecloth, to use a simple illustration, pushed along the surface of a table, even to the extent of being slightly separated from, and locally sliding over, the underlying rocks along a plane roughly about the top of the limestone.

The dense mass of the Alwars and the limestone would at first offer a great resistance to sharp folding and to the passage of this hypothetical plane of disturbance into them, and the fracture, if it took place at all, would be clear and narrow, while in the slates, since they are softer and more plastic under great pressure, crumpling, shearing and sliding would take place without necessarily any great amount of shattering. (The slate exposures are too scanty to show this properly.)

The Ajabgarhs which lie above, are, however, on account of their character of thin, brittle quartzites alternating with soft argillaceous bands, exactly the facies in which crumpling or irregular lateral slipping would produce its maximum effect in disrupting the beds. Being thin they are comparatively easily broken across, and the fragments are displaced up or down into the adjoining soft layers, which by separating the quartzites prevent them from forming a mutual support to each other.

Brecciation instead of folding.

In such a case, instead of folding into close corrugations or shearing along definite lines, we should have a jumbled mass of fragments where pressure has been intense, and less fractured blocks where it has locally been relieved, and we may conclude that by the conti-

nued action of compression a certain zone of brecciation might be formed in these quartzites, a zone which, though arising chiefly on one horizon, might deviate from it or bifurcate, giving rise to the phenomena of included bands of non-brecciated material, and of the breccia cutting diagonally across other beds.

Such a zone of loose material would be an easy path of access to intrusions of vein-quartz and to mineralising agents, aqueous or vapourous, introducing the silica and iron, with some manganese and copper, of the matrix. Fused quartz might even be produced *in situ* by the frictional heat evolved in crushing, as basic glass has been formed in the "trap-shotten gneiss" of Southern India¹; there are indications of this source, though not conclusive ones. The white quartz, in whatever way it originated, is itself often brecciated, which shows that the compressive forces have continued to act after its injection or formation *in situ*.

I have mentioned the shattered and quartz-veined appearance which the limestone sometimes has; it is strange that it was seen truly brecciated in only one instance, perhaps because such a rock may be unusually liable to denudation, and so is almost entirely concealed beneath alluvium.

If the causes suggested were sufficient to produce a band of crush-rock, necessarily varying considerably in thickness, in places not formed at all or only sparingly, and appearing on a horizon which differs somewhat from exact parallelism with the strata, even cutting across them or bifurcating in places, such a band or bands would, under folding, behave like a bedded rock, or, more exactly, like a sill. When the compressive stresses had become too great to be taken up merely by shearing and crushing, buckling would supervene and the breccia, along with the associated Alwars and Ajabgarhs, would be thrown into the steep folds which characterise this region, so that we now find it outcropping as an irregular bed following in the main the general strike but deviating somewhat from a fixed horizon.

Introduction of extraneous material.

Subsequent folding of breccia.

¹ Holland, *Mem., Geol. Surv. India*, XXVIII, pt. 2, p. 202.

CHAPTER VIII.

AJABGARH SERIES.

General Description.

Above the Kushalgarh limestone and passing conformably down into it, neglecting the occurrence of the hornstone breccia, is the immense thickness of beds comprised in the Ajabgarh Series of Hackett, the uppermost division of the Delhi System. It is in the country to the west of the present described area, Torawati and Shekhawati, that the best idea can be obtained of the composition and the thickness of the Ajabgarhs, for here the outcrops, although they cover in the aggregate a very large area, are disconnected and interrupted by expanses of alluvium, and much of the structural folding must necessarily be concealed by these alluvial plains.

Nevertheless, the available exposures are amply sufficient to give a correct idea of the constitution of this series.

It is owing to the preponderance of argillaceous rocks, soft and easily denuded in comparison with the massive Alwar quartzites, that the Ajabgarhs have their scattered and irregular distribution, occurring either in synclinal valleys folded into the main mass of the central hilly area of Alwar quartzites, or as lines and groups of hills in the plains to the west and east, near to or remote from the Alwars, but showing in their trend a general parallelism with the main tectonic lines displayed by them. Argillaceous rocks form by far the greater proportion of the series, varying according to their amount of alteration from shales to mica-schists, the commonest degree being that represented by splintery slates with imperfect cleavage, and silvery phyllites. In the latter staurolite, chistolite and small garnets are locally abundant.

As for the remainder, the general nature of the beds may best be described as indefinite, demanding the use of such terms as siliceous limestone, Limestones, grit, etc. ferruginous quartzite or calcareous slate, (sp. 22-310, sl. 6850, sp. 22-314, sl. 6854). Pure quartzites, such as are so common in the

Alwars, are rare, and conglomerates and pure limestones are unknown; in the whole of the Ajabgarhs examined only one local band of grit (sp. 22-275 sl. 6828) was met with, consisting of grains of quartz and pale brown mica in a matrix of carbonaceous calcite. This absence of gritty and conglomeratic quartzites is a radical distinction from the general character of the Alwars.

It is a striking fact that in such a great thickness of strata as the Ajabgarh Series there should be no beds representative of littoral deposition and none of the pure limestones which in post-Cambrian systems are taken as indicating deep-water accumulation. In the latter case however the uncertainty as to what extent pre-Cambrian limestones are organic in origin casts a certain amount of doubt on the supposition that the absence of pure limestone proves the non-existence of deep-sea conditions, but there is in the Ajabgarhs a total absence of that regularity of sedimentation and persistence of character laterally which one associates with beds laid down far from shore. As a whole they are either monotonous assemblages of slates or are thin impure quartzite beds intercalated with slates and siliceous limestones, showing a rapid alternation in character as one passes over the outcrops across the strike. Though adjoining beds may differ greatly, there is a total absence of recognisable horizons which can be traced for any distance, except in the case of the twisted quartzite ridge south-east of Alwar City, and even that is a group of strata several hundred feet thick and not a definite datum line.

Speaking generally, the Ajabgarh slates are black or rusty brown, often distinctly banded in differently coloured layers an inch or two thick, which do not weather differentially. Slaty cleavage is poorly developed but they are as a rule so adherent on their bedding planes that they can hardly be called shales (sp. 22-285, sl. 6834). Jointing is copious and irregular, the joints being frequently coated with deposited iron-oxides. When associated with bands of quartzite and conforming with them in general dip and strike, they are seen to be much more subject than the quartzites to minor wavings and crumplings. They weather into steep bare ridges with sharp crests and serrate peaks, usually black in colour and practically devoid of vegetation.

Under the microscope they are seen to be very fine-grained aggregates of quartz and cloudy aluminous and carbonaceous substance.

The quartzites are usually dark grey, or reddish from included iron oxides, and break with a conchoidal fracture; they are not so vitreous nor so close-textured as the typical Alwar quartzites and are darker in colour and more argillaceous. (Sp. 22-274, sl. 6827, sps. 22-276-7, sl. 6829.) They weather with a rather thick crust which tends to scale off easily, giving rise to sub-spherical blocks.

In the quartzites themselves stratification is all but invisible, but as they are comparatively thin and are interbedded with abundant slaty bands, it is distinctly seen in the mass. Jointing is sparing and is usually fairly rectangular. They do not form the bold dip-slopes of the Alwars, owing to their greater impurity and porosity and consequent ease of weathering, and also to the weakening of their structure by the interbedded slates. Scree-slopes are also less developed, for the fallen fragments disintegrate more rapidly into fine material which can be removed as rain-wash.

Microscopically they consist mainly of quartz in a closely inter-crystallised mosaic, cloudy black aluminous or carbonaceous material, and usually hæmatite in minute grains. Detrital muscovite, biotite and tourmaline often occur and calcite sometimes fills the spaces between the grains of quartz.

The slates or shales interbedded in the zones of quartzite are normally pale grey or dark grey in colour, soft, laminated, and almost devoid of slaty cleavage (sps. 22-270, 22-281-2, sls. 6831-2, sp. 22-286).

The Mandan Group.

Under this name ¹ Hacket has included a double ridge running some fifteen miles north-north-east from Mandaor (not Mandawar) and a large number of exposures in the north-west of the area, near Mandan, Tasing and Barod, indicating their similarity to the Ajabgarh Series —“ the Ajabgarh slates containing andalusite, etc., in the hill east of Alwar, as well as the quartzites, are very similar

Identity with Ajabgarhs.

¹ *Rec., Geol. Surv. India*, X, pt. 2, p. 89.

to those of the Mándán group." In my opinion there is no doubt of their identity.

Apart from their close lithological similarity direct evidence of their equivalence is given by two sections, near Barod and near Mandaor.

The ridge at Barod, phyllites, dips westwards at about 80° and is separated by about 1,000 yards of alluvium from a hill in which crystalline limestone, the Kushalgarh limestone, horizontal and dipping eastward at low angles, is succeeded above by undoubted hornstone breccia. About half a mile of alluvium intervenes between this and the next ridge, slate rather than phyllite, which is practically vertical, or if anything, dips to the east. This would seem to be an anticlinal isocline, in which the almost horizontal limestone on the crest is the oldest bed seen.

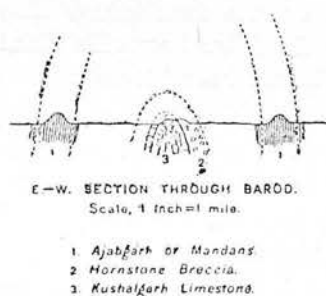


FIG. 6.

Indications of the continuation of this anticline are seen in the Nimrana hills seven miles to the north along its axis, but the axis has pitched downwards and only the phyllites are exposed.

At Mandaor the position of the Mandans between two ridges of Alwar quartzite, dipping towards each other and converging to the south, would indicate that they overlie the Alwars, the Kushalgarh limestone either being absent or concealed by alluvium. In the case of Barod we have an anticline in which they rest upon the Kushalgarh limestone and the breccia, at Mandaor they occupy a syncline in the Alwars, quite sufficient proof I think that they are on the same horizon as, and

identical with, the Ajabgarhs. (Ajabgarh Series—sps. 22-270-294, sls. 6824-39, sps. 23-104-112, sls. 7649-52.)

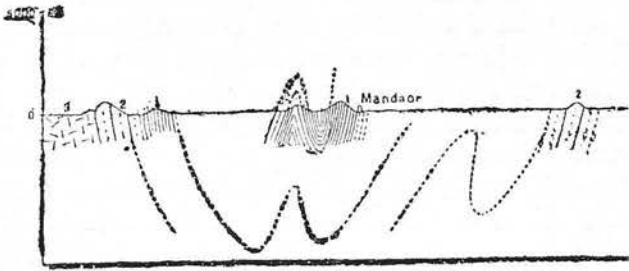


FIG. 7.—E. W. section through Mandaor. Scale 1 inch = 1 mile 1. Ajabgarhs, 2. Alwars, 3. Pre-Delhi Granite.

Detailed Description.

In my account of the Alwars (p. 34) I have described the elongated mass of hills running south from Delhi to near Noganwa. An important area of Ajabgarhs is found to the east of this, *i.e.*, between it and the Alwars surrounding Kaman, and to the south-east of Kaman are a few small exposures at Dig, Kumher, Gobardhan and Bharatpur. West of the Noganwa-Delhi ridge and east of that portion of the central hill-mass which lies north of Alwar City are several clusters of Ajabgarh hills which can be followed, in spite of alluvial interruptions, into the Deoti valley and the sinuous ridges traversing the south-east corner of the Alwar State, and also into the Delawas and Kushalgarh valleys. From the latter the connection with the Ajabgarh syncline is unbroken. To the north the Ajabgarh valley opens on the plains drained by the Sabi and the Sota rivers, where the Ajabgarhs are well represented by numerous and large groups of hills mapped by Hackett as the Mandans.

Were the alluvial mantle removed we should probably find that the Ajabgarhs covered in the aggregate a much greater area than the Alwars and that the latter, as is well seen in the Torawati and Shekhawati hills, were interdigitating brachyantiforms folded up through an intensely corrugated mass of Ajabgarhs along certain axes of maximum uplift. As it is, the more extensive erosion of the Ajabgarhs and their concealment over large areas, gives one the incorrect idea that the Alwars are the more important and that the

former are represented by synclines caught up in an anticlinorium of the latter.

Taking up the exposures in the order just indicated, the first to be described is a straight and narrow band of Gurgaon District. Ajabgarh outcrops running through the southern part of Gurgaon District and thence into the extreme north-east of Bharatpur State, adjoined to the east by scattered hills arranged in curving lines and belonging to the same series. For many miles from its northern termination near Mandkaula it runs as two very narrow ridges half a mile apart. As thus seen I took them for Alwars, which they exactly resemble, and it is not until they are followed to the south that their real nature is apparent.

At Mándkaula they are regularly and thinly bedded, fine-grained, pale grey and white quartzites, vitreous and sparingly jointed; stratification and false-bedding are shown by lines of darker material.

In some small detached outcrops north and east of Hathin, similar beds are seen, with some very coarsely granular and glassy, white and pale bluish quartzite, like those of the hills south of Delhi and, like them, weathering into a pinkish grit.

The strike of the Mandkaula ridges is north-north-east, as straight as if drawn by a ruler, but the dip appears to be very variable, from "surface creep" acting on strata which are really vertical or nearly so.

From Pinangwan southwards, a broadening of the ridges takes place by the appearance from below the alluvium of softer beds and it is found that these quartzites are merely ribs of less easily denuded rock among what are almost certainly Ajabgarhs. It is evident that disconnected areas such as these, where fossils are absent, where the evidence of lithological similarity is strained by the distance between them and known rocks, and the rocks themselves are variable, can never be actually proved to be of one age or another, and identification must be to some extent a matter of personal opinion, guided by such similarities as exist and such variations as are known to occur.

An almost complete section is available, and comprises an alternation of slates and quartzites, the valleys formed along bands of knotted but soft and uncrystallised grey and brown slates, and the ridges between built up of alternating quartzites and slates, the latter often streaked with thin laminae of quartzite, projecting on weathering.

The quartzites are paler in colour than the usual Ajabgarhs (though dark beds do occur), fine-grained, crystalline and somewhat argillaceous; as the intercalated slates are rather harder than the normal, the ridges have not the longitudinally ribbed appearance which is so common (see p. 81), due to differential weathering. The separate beds are however well-marked. As a rule they are very thinly bedded or flaggy, but rapid alternations of quartzite and slate are not so frequent as in the Ajabgarhs in the south-east of Alwar State. They disintegrate into hard fragments which retain their angularity. There are four main zones of quartzite, the first two of which, counting from the west, are straight and continuous, the third and fourth curve away in great loops from these at Biwan, and are more interrupted.



FIG. 8.—Ajabgarh quartzite ridges in S. Gurgaon.

Between these are slate bands, that between the third and fourth being inferred rather than seen; the slates between the second and third are expanded by a double fold north of Biwan, into the extensive group of hills south of Pinangwan, very low and rolling, of brown, grey and olive slates slightly krotted.

Bedding is obscured by the regular cleavage, regular both in strike and dip despite the great folds in which the rocks really lie. These slates are worked for local uses in numerous small quarries, but are too soft and do not split thinly enough to compete successfully in the market as a roofing or flooring material (sp. 24-639).

In the western portion of these slate hills there is a great deal of white quartz veining, which is absent from the other slate bands and the quartzite ridges. In the extreme south the slates are replaced by black graphitic schists.

The mythologically renowned "Ghiraj" (King of Mountains) at Gobardhan is a straight, low, narrow ridge of dark-coloured, quadrangularly jointed, crystalline quartzites, the classification of which is doubtful but which I have mapped as Ajabgarhs, as they are similar to, and along the same strike as, the Ajabgarhs west of Bharatpur. They dip regularly to the north-west at 20° .

Immediately to the south-west of Dig is a small group of low hills of almost horizontal, slightly rolling black slates, in which some of the beds are slightly siliceous. Hackett¹ describes them as "capped by a few beds of Alwar quartzite" but this is certainly not the case.

South-west of Kumher and west of Bharatpur are two north-east-south-west striking ridges of black slates and dark rusty quartzites, with interbedded phyllites and soft grey kaolinitic rock, very typical Ajabgarhs. At the north end of the latter ridge are numerous white quartz veins in a fine-grained, black, unbedded quartzite.

The line of short ridges and detached hills running for about twelve miles south by west from Noganwa is the remnant of an anticline of soft, dark quartzites and slates, showing their folded structure with great distinctness on account of their heterogeneous nature, and in common with most of the Ajabgarhs, much subject to minor oscillations in dip and strike.

Next we pass to the T shaped mass of hills west of Ramgarh, in which the general dip is away from the low quaquaversal dome of Alwars at Saroli. In their height and in the considerable amount of alteration which they have undergone they resemble those near Mandaor (p. 83). The quartzites are vitreous or schistose, and in the slates chialiolite and staurolite occur.

A mile of alluvium intervenes between this and the two long ridges enclosing an oval valley and extending north some seventeen miles to Deotana. The western and broader has a constant westward dip, though varying

¹ *Rec., Geol. Surv. India*, XIV, pt. 4, p. 287.

in degree, the other is inclined steeply in the opposite direction in the south, but swings through verticality to a westward dip, which persists, with one or two variations, to its northern termination. If this be an anticline, as would appear from the structure of its southern end, then the same rocks, where they must curve up again in parallelism with the Alwars, are concealed except north-east of Kithur; there the twisted ridge south of Kolgaon meets the main ridge at the head of a long valley, which probably marks the intervening syncline.

In type the strata of these hills show some approximation to the Alwars. Slaty bands between the quartzites are less numerous and the quartzites themselves are harder and slightly purer, consequently they are not unlike hills of Alwars, except for their darker colour, and that the ribbed appearance is present, though masked.

The most prominent rock-type is a pale grey quartzite, rough in grain like the Berla stone (p. 82), but more metamorphosed and copiously blotched with iron-staining. (Sps. 23-109-10, sls. 7650-1).

The sinuous ridges which traverse the south-eastern corner of the Alwar State may be said to commence at Alwar City. Though not absolutely continuous in their outcrops, they nevertheless follow the strike of the Alwars with much persistence and form a narrow twisting ridge, steep-sided, and rising and falling gently in profile, with a maximum elevation of about five hundred feet above the plain.

Their appearance on the geological map with regard to the Alwars reminds one of the text-book diagrams of a barrier coral reef following an irregular coast-line, their distance from the Alwars varying considerably, presumably owing to irregular rolls and flexures in the intervening rocks, to which the Ajabgarhs seem notably subject. They consist of rapid alternations of quartzites or quartzitic sandstones and soft slaty or shaly bands, the former up to six feet or more in thickness and the argillaceous bands usually less.

The quartzites, being much harder, stand out on weathering like low walls along the strike, giving the ridge a striking and characteristic longitudinally ribbed aspect (Pls. 12, fig. 2, 13, fig. 1), distinguishing them at a distance from the Alwars, which, though similarly bedded, are homogeneous and do not take on this peculiar aspect.

Though maintaining generally the local dip and strike, they are very subject to minor twistings, and swingings of their inclination

from one side to the other of verticality, so their ridge has a curiously serpentine form when looked at on the map, or in the field from some eminence. Also, instead of forming a single ridge, they are sometimes seen folded into a set of small anticlines and synclines, as in the Loharwari group of hills, south of Ghat, south of Chaome and north of the Deoti Lake. (Pl. 12, fig. 1.)

The thickness of this mixed zone of quartzites and slates seems fairly constant throughout and is about eight hundred feet. A detailed description of the outcrops is superfluous. Their variation in character vertically is great but their general facies is so constant that the above remarks, with those in the general description (pp. 73-75) will apply almost anywhere along the strike.

The rock called the Berla quartzite by Hacket deserves separate mention from its peculiar texture and its economic importance. (Sps. 22-271-2, sls. 6824-5, sp. 22-283, sl. 6833.)

It varies from white to dark grey in various pleasing shades, with specks of magnetite and tourmaline, and forms a zone of several bands in total thickness eighty or a hundred feet, about the middle of the quartzites of the above ridge, along which it seems to be continuous. It is porous, harsh in texture and granular, and might, from a hand specimen, be described as a sandstone. Microscopically it has a spongy texture, with numerous spaces between the quartz grains partially filled with kaolin and secondary quartz. (Pl. 14, fig. 3.) Probably it is a calcareous sandstone, altered to quartzite, which has had its calcite subsequently removed, leaving a quartz skeleton. It is soft yet tough, free from joints or flaws or unsightly markings, can be got out in large blocks and, being of a pleasing colour, makes an excellent building stone for such works as bridges and railway station buildings.

At present it is extensively quarried at many places along the ridge, for masonry and for such articles as basins and platters, hand-mills (chakki) for grinding corn, large mortars and rollers, its gritty texture and the ease with which it can be chiselled rendering it admirable for these purposes.

In the Deoti Lake syncline slates are exposed below the zone of quartzites on both sides of the valley, on the west as black slates of the general type, on the east below the small uneven plateau formed of undulating Ajabgarh quartzites, and passing into the Kushalgarh limestone by insensible gradations.

Slates below quartzite zone.

Sweeping round the head of the valley they appear again south of the lake between the Ajabgarh quartzites and the Kushalgarh limestone, outcropping at intervals among the debris of the former, below the scarp. All along they are brecciated, these occurrences being noted in the description of the hornstone breccia (p. 66). Their thickness here is two to three hundred feet.

In the middle of the anticlinal loop of Ajabgarh quartzites stretching north-east from Gugrod and in the parallel loop to the south-east, the slates form isolated hills protruding from the alluvium, alone or associated with the hornstone breccia and the Kushalgarh limestone, as has been described (p. 61-66). In the second loop they are particularly prominent, forming groups of conspicuous black hills stretching north-north-east from Jamroli for about thirteen miles. They are also seen, to a much less extent, in the next anticline to the south-east, above the Alwar grits of the Reni "bay." The thickness here is apparently greater than in the Deoti syncline, but as the slates are much corrugated and neither top nor base is exposed, it cannot be estimated.

The double ridge running for about fifteen miles north-north-east from Mandaor, included by Hackett in his Mandan Series, consists of quartzites interbedded with phyllites or mica schists, dipping vertically or at very high angles. The quartzites are reddish or dark grey in colour and are indistinguishable from the more metamorphosed types of the Ajabgarhs. The phyllites (sps. 22-291 and 293, sls. 6836 and 6838) are hard, silvery, slightly ferruginous and very fissile, and are interbedded with the quartzites in the manner which characterises the Ajabgarh ridge just described, though here, owing to the lesser difference in hardness of the argillaceous and siliceous bands, the ribbed appearance is not so pronounced but is still noticeable. The former predominate in the central valley between the ridges (which owe their prominence to the more abundant quartzite bands in them), appearing in parts of the central area, where they have locally escaped metamorphism, as black slates exactly similar to the typical Ajabgarh slates but containing large crystals of chialstolite (sp. 22-292, sl. 6837) as long as four inches. Cruciform twins of staurolite are common and are developed in the planes of foliation in preference to the bedding-planes, where the two are not coincident. Injected vein quartz is rather common in these hills. Pl. 11, fig. 2 shows the outcrop of a quartz "sill," splitting, along the bedding-planes, into several branches.

Though they form a syncline folded into the Alwar quartzites, it is not a simple syncline, for in several sections some of the beds are repeated in closely pressed folds. (Pl. 12, fig. 1.)

South from Alipur the broken line of Alwar outcrops north of the railway expands for a short distance and then runs as a narrow ridge into the Jaipur State. It is high on the west, where it is composed of quartzites, and lower on the east, where slates predominate.

In the "Manual of the Geology of India" (p. 69) part of the latter is described as "beds of compact siliceous rock and jasper, slightly resembling those of the Gwalior system, are recorded near Muhammadpur, south of Kherly railway station."

They can hardly be called jasper, being merely fine, compact ferruginous quartzites, and are certainly conformable with the quartzite beds against them to the west. In their appearance there is nothing against placing them with the Alwars or the passage beds between the Alwars and the Kushalgarh limestone.

The quartzites forming the higher portion of the range are almost certainly Alwars, and the detached hillocks to the east, at its base, are typical Ajabgarh slates. The section is interrupted at the horizon of the Kushalgarh limestone, so it is uncertain whether this is present or is replaced by slates.

Dips are all to west-north-west at 50° - 80° , i.e., if my interpretation of the section is correct the Alwars are inverted over the Ajabgarhs, as often happens.

Passing now to the synclines infolded in the Alwars, the quartzitic zone of the Ajabgarhs is well exposed but the slates are almost entirely covered. They are in part represented as the band of fine black quartzite, described in connection with the hornstone breccia (p. 68), which is in places graphitic, soiling the fingers (sp. 22-278). A mile north-west of Delawas, a mica-schist with garnets occurs locally at about this horizon (sp. 22-279).

In the same area, the Ajabgarh valley, there is a considerable variation in the series from its aspect in the Deoti valley and the eastern plains. Instead of the zone of quartzites being sharply marked off from the slates, there is here no such division, and the floor of the valley is dotted with lines and clusters of small hills of interbedded soft, dark, aluminous quartzites and argillaceous rocks, frequently very calcareous. In general the dip is westwards, since the valley is excavated

along an isoclinal syncline the axial plane of which is inclined to the west.

In the central part of the valley the beds are chiefly argillaceous, with frequent but thin quartzites ; the sides are occupied by a great development of limestones, which on the east side are well-bedded and very similar to, and pass gradually downwards into, the Kushalgarh limestone. On the whole however they are more siliceous and so form hills two and three hundred feet above the plain, which the Kushalgarh limestone never does.

The hornstone breccia here occurs above these, not between them and the Kushalgarh limestone. On the other side of the valley are corresponding large limestone exposures, but their character has been completely changed, perhaps by some concealed granite intrusion analogous to those between this locality and Bairat.

Instead of being banded along the lines of deposition, the rock is crystalline and is frequently almost entirely a mass of tremolite in felted fibres. Quartz veins and stringers are in great profusion ; whether these are injected or are simply the siliceous material of the limestone, dissolved and segregated, I am unable to say.

They dip (though they are highly crystalline, bedding is sometimes apparent) below mounds composed in part probably of fragments of the quartz veins of the limestone, which have been left on the removal of the latter, and in part of the hornstone breccia ; *i.e.*, the breccia is here at about the top of the Kushalgarh limestone, which is inverted above the Ajabgarhs. Followed southward these calcareous rocks are replaced by slates along the strike ; in the northern part of the valley, where they attain their greatest width of outcrop, they are probably repeated by folding along the axes of two anticlines in the Alwars parallel to the Ajabgarh syncline, one passing through Suratgarh, the other about two miles to the west (pp. 53).

In the southern part of the valley calcareous rocks and quartzites above the Kushalgarh limestone are absent.

The mass of small hills north of Ajabgarh is entirely of black slates, indistinctly cleaved, with several narrow zones of brecciation running along them.

The Ajabgarhs of the Partabgarh syncline are practically all impure quartzites without slates or limestones.

Partabgarh.

Those in the Bairas branch of the main valley approach in type the impure limestones of the latter's northern part, but are less distinctly banded.

Bairas.

To the north of the Ajabgarh valley are numerous outcrops of Hacket's Mandan Series, isolated hills and interrupted ridges trending north-east—south-west to north-north-east—south-south-west.

Khori.

The most southerly are at Khori, where they seem to continue the rocks of the Ajabgarh valley but are more than ten miles distant, very thin-bedded, almost slaty, quartzites, with subordinate slates, much twisted in strike.

Jointing is extremely close and irregular, so that they appear shattered; these joints have carried up iron-ores to such an extent that little of the white colour of the quartzites has been left.

2½ miles north-east of this, at Girari, is a hill of silvery and red phyllites.

At Mahanpur is a long and high ridge of phyllites, black or dark grey, rich in staurolite and small garnets.

Mahanpur.

Cleavage, so far as was seen, coincides with bedding; the phyllites are not very fissile and are copiously jointed. Several small flanking hills to the north-east, and those at the south end of the ridge, are of slates and soft, rusty, slaty quartzite. The continuity of this ridge with that rising from the Sabi river east of Barod is indicated by three small intermediate outcrops of similar phyllites, in the same line.

The Barod section has been described (p. 76).

From Nimrana a large mass of hills runs north-eastwards for about fifteen miles, a compact group at their commencement, but rapidly dying out into

Nimrana.

narrow broken ridges, cut up by longitudinal and transverse valleys filled with blown sand. Their general dip is to the north-west at high angles. They are on a lower horizon than the Barod hills and differ from them in having numerous runs of dark, fine-grained quartzite intercalated in the slates. The latter also are often rather siliceous and are copiously impregnated with iron-ore along joints and bedding planes (as are also the quartzites), which projects on weathered surfaces. In many places the siliceous bands give the hills a ribbed appearance very like that of the Ajabgarhs in the south-east, but as a rule they are steep, high, and serrated, and give in their outward form little indication of their structure; both

quartzites and phyllites break up into hard angular fragments which disintegrate slowly and smother the lower slopes in scree-material.

In these hills, as in those of Barod, thick ferruginous quartz veins and sills are common; a very rich one, almost pure hæmatite, was seen 1 mile south-east of Ghilod, about six feet thick, but is visible only for a short distance along the strike.

Several hillocks on the boundary between Gurgaon and Rohtak Districts lie on their strike far to the north, and to the east is a group of numerous exactly similar hills north of Tankri.

West of the Nimrana range are the three hill-groups at Tasing, Mandan and Kund railway station, forming a geologically continuous division of slates or indurated shales, without quartzites, striking with fair uniformity north-north-east—south-south-west to north-east—south-west, and almost vertical, or dipping west-north-west and north-west at high angles.

They are probably the youngest Ajabgarhs in the area, about the centre of a geosyncline extending from Barod to the Alwars in Torawati and Narnaul, at least so the dips in the adjoining outcrops would indicate. As a rule they are dark grey ("slate-coloured"), sometimes pinkish-brown and olive. Cleavage is not very perfect, but at Kund, where there are extensive quarries, cleavage and bedding coincide, producing really a hardened shale, splitting admirably along the lamination.

The quarries are worked by the Kangra Valley Slate Co. and other companies, and produce large quantities of excellent roofing and flooring slates. There are also quarries at Mandan, but here the slates are not nearly so good, being softer and more abundantly jointed.

CHAPTER IX.

IGNEOUS ROCKS INTRUSIVE IN THE DELHI SYSTEM.

The igneous bodies intrusive in the rocks of the Delhi System are of three kinds, quite distinct from each other in age and in character, and not varying greatly within the limits of the groups.

Types. Arranged according to their period of intrusion they are:—

3. Pegmatite veins.
2. Granite bosses.
1. Amphibolite sills and veins (trap).

In this area these intrusives are not so strongly developed as in the country to the west, Shekhawati and Torawati.

My opinions as to their nature and their ages were, however, formed from the country I am describing and were confirmed in full when I subsequently had an opportunity of examining the more numerous and clearer exposures in Shekhawati and Torawati.

The pegmatites are indirectly shown to be the youngest by the fact that they are *never* foliated nor crushed, showing that they were intruded when folding had ceased, while the amphibolites are sometimes schistose, sometimes not, and the granite bosses always show some foliation, varying greatly in degree.

That the pegmatites are later than the traps is directly proved by a zone of trap injection north of Buchara (in Torawati, beyond the limits of this area), cut through in all directions by pegmatite veins. Their relation to the granite is seen in the Jainthpura boss (in Shekhawati), across which they cut at its south end and at its north end near Raipur, and also in the Bechun hills west of Jaipur. As to the granites and the traps, $1\frac{1}{2}$ miles south of Bairat numerous veins of fine granite were observed penetrating the trap adjoining the boss, and the great Chapoli granite mass in Shekhawati includes numerous xenoliths of trap associated with still more abundant quartzite fragments also derived from the invaded strata.

It is strange that the amphibolites, though they are older than the granites and should accordingly show more signs of compression, are seldom schistose, while the latter are typically foliated; probably the reason is that the amphibolites have been completely

recrystallised and reconstructed from their original states as diorites or dolerites, all pyroxenes, etc., altering to hornblende.

These changes would quite likely continue until pressure and folding had almost ceased, since amphiboles and pyroxenes are somewhat unstable minerals, so that the mechanical effects of compression have been obliterated by the accompanying and subsequent chemical alteration. The granites, though they were intruded at a later stage, during folding, are largely composed of quartz and felspar, minerals which are chemically much more stable and less alterable than ferro-magnesian and so have not undergone recrystallisation and have retained the evidences of mechanical strain induced during or after solidification.

Their temperature and fluidity conditions at the time of intrusion must also have been very different, as the traps minutely permeate their country rock in strings and thin layers, while the granite forms large masses with sharply defined margins and rarely sends out apophyses. The pegmatites have an intermediate character, for their veins, though ramifying, are of large size and meet the enclosing rocks sharply and without any *lit-par-lit* injection.

In the pre-Delhi rocks of the Baswa, Raialo and Reni "bays" there are also granite, pegmatite and amphibolite, but the granite and pegmatite are clearly older than the oldest Delhis, which rest on their eroded surface; the amphibolite is probably the same as that in the Delhis, since in one or two cases it is seen to pass beyond the basal unconformity into the Raialo quartzite. The dykes and veins which so copiously seam the pre-Delhi granite south of Raialo and Bhangarh are no doubt part of the system of feeders which supplied the sills in the Alwar quartzites.

In this area the intrusives of all three types are practically confined to the Alwars; this, however, is merely
 Chiefly in Alwar Series. because the injecting forces have not been powerful enough to thrust them to higher levels, or perhaps they are present but do not appear because of the comparative paucity of Ajabgarh outcrops; it is not due to their having been injected before the Ajabgarhs were laid down, for to the west we find the Ajabgarhs much invaded by igneous rocks identical in character and almost certainly of the same age.

In this area the amphibolites, however, seem to be confined to the Alwars, and if the three bands near the Siliberi Kho are really

effusives, they would seem to be contemporaneous in their period of effusion and injection with the deposition of the middle Alwars, but in Torawati they are found extending upwards into the Ajabgarhs. In Torawati therefore they must belong in part to a later period of intrusion.

1. Amphibolites.

The field relations of the amphibolites or traps have been described in the chapter on the Alwar Series (Chap. V, pp. 38-55). In colour they are dark green or black, with a small amount of the white minerals usually showing in hand specimens, and are visibly crystalline, homogeneous, unstratified and seldom schistose. The coarseness of grain varies greatly and has no relation to the dimensions of their mass. Under the microscope they are seen to consist chiefly of hypidiomorphic green hornblende with interstitial quartz and clear felspar. Their structure may be described as granulitic ¹ (without implying that the rock has originated by crushing) and non-porphyrific.

Sphene and apatite invariably accompany the hornblende, but in small quantity, the former, in part at least, secondary after ilmenite, which also occurs. Exceptionally quartz and felspar are absent, the rock then consisting entirely of ferro-magnesian minerals.

Plagioclase is more frequent than orthoclase; either or both may occur, with or without quartz. When the felspars are quite clear and untwinned, as they often are, they cannot be easily distinguished from quartz. I found Becke's staining method ² useful to identify them, in which the section is etched with hydrofluoric acid and stained with aniline blue. Plagioclase is strongly, and orthoclase slightly, coloured and quartz remains unchanged.

A small amount of scaly decomposition product characterises the felspars in some cases, but in general their freshness is striking.

As accessories biotite and well-formed pink garnets occur; the latter I consider to be extraneous, caught up from the invaded rocks, which in these cases are garnetiferous mica-schists.

It is found that bands of mica-schist and conglomerates with a micaceous matrix are favoured, in comparison with quartzites, as an avenue of injection,

Manner of intrusion.

¹ Harker, *Petrology*, 3rd Ed., pp. 25, 323, 334.

² Harker, *Petrology*, 3rd Ed., p. 290.

from obvious mechanical reasons, while in limestones it would appear (I suggest this with all caution) that the thinner trap sills and veins are to some extent absorbed, with mutual chemical reactions resulting in the formation of actinolite, tremolite and epidote.

In several places the streaks of amphibole along the bedding planes of quartzites are so straight and regular, so numerous and so thin, that they strongly suggest lines of metamorphosed volcanic dust, augite tuff for instance. The supposition that some of the amphibolite bands are altered tuffs or contemporaneous flows, *e.g.*, north of Siliberi Kho, does not of course negative the indubitable proofs that the majority are hypabyssal. It is only to be expected that an extensive system of intrusive rocks might be represented on the surface by ejected lavas and tuff of the same magmatic origin.

Where they are thick enough to give rise to scenic features, for instance in the Tehla valley, they form
 Topography. rounded hillocks of no great height, covered with spheroidally weathered blocks and supporting luxuriant grass. They produce a rich soil not unlike black cotton soil.

The granulitic structure of the amphibolites cannot have arisen during the original consolidation, as the minerals
 Origin. which now occur were formed long after this, but is probably the final result of compression, and is contemporaneous with the foliation of the surrounding rocks, shearing and schistosity being induced in yielding rocks like mica or chlorite schists while in stronger and tougher rocks like amphibolite and quartzite granulation and recrystallisation took place.

The origin of the amphibolites is probably a number of different types of dioritic or doleritic composition, but unlike other instances¹ in which the change has been traced through intermediate steps, here the conversion of pyroxene into hornblende has been in all

¹ *Bull. U. S. Geol. Survey*, No. 62, Ch. 1.

Q. J. G. S., xlv, pp. 429-435.

Q. J. G. S., xli, pp. 133-144.

Blake, *Rep., Brit. Assn. for 1888*, p. 406.

Teall, *Brit. Petrography*, pls. XXVIII and XL, fig. 2.

Rec., Geol. Surv. India, XLIII, pt. 1, p. 35.

Adams and Barlow "Haliburton and Bancroft Areas," pp. 62-68, 97-127, 157-172.

Lévy, *Bull., Soc. Geol. France* (1883), p. 916.

Bull. Carte Geol., France, V (1893), p. 337.

Cole *Trans. R. Irish Acad.*, XXXI (1900), p. 453.

cases complete; in none of the many specimens examined is there any trace of the original pyroxene.

Adams and Barlow (loc. cit.) have described a similar but much more extensive development of amphibolites, which they show have been produced on the one hand by the alteration of basic igneous intrusions, and on the other hand by the action of granitic intrusions on limestones.

In my area I have not observed any cases which could be with certainty included in the latter class, though the outcrop at Beroj (p. 39) may be of this character.

Sometimes the bladed and felted tremolite masses in the altered limestones strongly resemble "feather amphibolite" (loc. cit., Pl. XXXVII), but these crystals are imbedded in the calcite of the limestone and not in a special feldspathic modification, as in the examples of Adams and Barlow.

Here, of course, metamorphism has not been nearly so severe as in the Haliburton and Bancroft areas, and the alteration of the limestones has not gone any farther than the production of bladed and asbestiform amphiboles in coarsely crystalline calcite, without other minerals such as pyroxene and feldspars.

(Amphibolites—sps. 23·81-97, sls. 7629-45.)

2. Granites.

The granites occur in a number of sharply-margined bosses, more or less lenticular in plan, in this area
 Characteristics and composition. confined to the Alwar Series but farther to the west found penetrating the Ajabgarhs also.

The chief variations among the different masses, apart from size, are in the degree of foliation, the coarseness or fineness of grain, and the presence or absence of porphyritic crystals of feldspar.

Examined under the microscope they show quartz, microcline or orthoclase or both, biotite in variable quantity and often a small amount of acid plagioclase; sphene (with ilmenite) is prominent and other accessories are apatite and muscovite.

Unlike the pre-Delhi granites, these are quite free from amphibolite dykes and pegmatite (pp. 16, 18); microgranite or quartz veins are seldom met with in them.

In his first paper¹ Hackett apparently did not recognize these masses as granite, for he writes of them as "arkose"; on the map

¹ *Rec., Geol. Surv. India*, X, pt. 2, p. 86.

accompanying his second¹ paper he indicates several of them as gneiss, but did not differentiate them from the much older granite below the base of the Alwars.

The first of the bosses which I examined is that at Dadīkar, west of Alwar City, the field relations of which have been described (p. 40). It is a coarse, porphyritic rock, consisting of microcline, orthoclase, quartz (micropegmatite) and biotite, with sphene and apatite. (Sps. 22-350-1, sls. 6-883-4.) It is pink in colour, with small streaks of black biotite, has fairly large orthoclase phenocrysts and is locally well foliated in a N. and S. direction, consistent with the strike of the adjacent quartzites. It is devoid of pegmatite veins but includes a few bands of hematitic quartz, near its eastern margin. (Sp. 22-334, sl. 6869.)

The largest and most instructive of the granites is that which forms a number of small hills protruding from the alluvium surrounding the town of Bairat. (pp. 53-54). Its central part has been denuded and is concealed, but round the margin its junction with the Alwars is clearly seen in several places.

It is a coarse grained rock, uniform in texture, porphyritic in only a few limited areas and is very obscurely foliated. (Sps. 23-44-7, sls. 7597-7600.) Two small veins of tourmaline-pegmatite were observed in it and on its eastern side a few quartz-veins cross it; these latter are subsequent to consolidation, for they run along almost straight lines, probably joints.

It never contains much biotite and is frequently quite free from mica; an unusual accessory is fluorite (sls. 7599-7600) in specimens from its eastern margin. Sphene seems to be absent.

Most of the felspar is white, but numerous large irregular or rounded areas are seen in which the felspar is pink, and in some localities the rock as a whole is coloured red by small quantities of diffused ferruginous material. On weathering a very rough surface is produced, with the formation of great bare domes and picturesque "tors" of enormous rounded boulders.

Examined under the microscope it is seen to contain quartz, kaolinised orthoclase, microcline, a little plagioclase, biotite, muscovite and fluorite.

¹ *Rec., Geol. Surv. India*, XIV, pt. 4.

It is very clearly an intrusive boss, as the following observations will show.

At both ends of the Papra hill, N. E. of Bairat, quartzites are seen striking at an angle to the granite margin and cut off sharply by it.

Near the centre of the hill granite is in contact with what looks at first sight like a conglomerate of quartzite pebbles in a hornblendic matrix, but this is merely a case of amphibolite injection, the quartzite fragments apparently being rounded by its corrosive action. They are flat and tile-like and some are twisted; one was seen in which the amphibolite had forced its way in thin films along the laminae of the quartzite. A large tongue of granite projects into this rock.

There are several true conglomerates interbedded with the Alwars in the neighbourhood of Bairat, but they are never arkose nor do they contain granite pebbles, and are not found in the field in such positions as to lend any probability to the suggestion that the granite is a pre-Delhi one and that these conglomerates are basal beds marking an unconformity above it. Besides, the evidence pointing to its intrusive nature is quite conclusive.

Just W. of Papri, a village about a mile W. N. W. of Bairat, are two small oval plugs of granite, one of them completely surrounded by quartzite, which have between them brecciated quartzite injected with fine-grained granite veins. A similar breccia is seen $1\frac{1}{2}$ miles W. of Bairat, lying as a flat sheet on the granite. $\frac{3}{4}$ m. N. of Papri another junction is seen, the granite sending short broad tongues into the quartzites and containing within its margin a few xenoliths of quartzite. $1\frac{1}{2}$ m. S. of Bairat granite and trap meet, with numerous fine-grained granite veins penetrating the latter and proving that it is the earlier of the two.

Another very similar but smaller intrusion (that of Basi) lies
 Basi. about two miles south of this, essentially the same in composition but having sphene and apatite as accessories, without muscovite or fluorite; it is very variable in grain, and very micaceous. In colour it is both white and pink and is foliated in a N. and S. direction, becoming markedly schistose near its margin. Phenocrysts are abundant even in the very fine-grained stuff, but they are not of large size nor well-formed. Only one small pegmatite vein (with tourmaline) and a few quartz veins were observed in the whole mass. The sedimentary rocks

around, as about the Bairat mass, are crowded with amphibolite bands but none appear in the granite.

Areas of the fine-grained rock are seen to terminate sharply against the coarser stuff but the two mutually interpenetrate, and they are identical in mineral composition.

The topography it forms is the same as that of Dadikar and Bairat, an oval valley, soil-covered in the centre, with a few projecting knolls of granite, which extends far up the sides under the surrounding quartzites.

On its west and south margins the granite becomes schistose and appears to pass gradually into a banded amphibolite and that into the normal quartzites, at least no definite lines could be drawn dividing them. There is no sign of a conglomerate. To the east it terminates against soft mica schists, traversed by numerous dykes of amphibolite and veins of quartz and quartz-tourmaline rock. The schists are locally more highly altered near the granite, and contain staurolite and garnets. The latter occur in the amphibolite dykes as well.

The arguments in favour of this exposure being an intrusive are, briefly :—

- (a) its petrological identity and therefore probable identity in age, with the Bairat and Dadikar masses, which are certainly intruded ;
- (b) the absence of any unconformity conglomerate round its edge ;
- (c) its freedom from amphibolite intrusions, in striking contrast to the rocks in its immediate vicinity, showing that it is of an age subsequent to that in which they were injected ;
- (d) the locally increased metamorphism of these sedimentaries near the granite ;
- (e) the nature of its boundary with the surrounding rocks, with observed cases of inclusion of highly altered quartzite in it and penetration of the schists by it.

In the remaining occurrences the relation of the granite to the Delhi is not seen, owing to the alluvial mantle, but from their similarity to those just described and other indirect evidence, there is little doubt that they also are intrusive and are of the same age and magmatic origin as those of Dadikar and Bairat, and the still

more numerous, extensive and well exposed bosses in Torawati and Shekhawati.

On the sandy plains to the north near Harsora is a group of high and rugged hills, recognizable as granite from a great distance by their characteristic form. There are three main masses, with a number of smaller ones; they are separated from each other by alluvium but probably all belong to the same body, which, if this is so, must be very large.

The most southerly, Ladpur Rock, consists of both the basic variety, rich in biotite, of Dadīkar and Basi, and the more acid mica-free modification seen in parts of the Bairat mass; they alternate in four somewhat indefinite zones running N. and S.

The basic type (sp. 23·49, sl. 7602) is devoid of quartz-veins or pegmatites and consists as usual of quartz, orthoclase phenocrysts, microcline, biotite, sphene and apatite. Foliation (about N. and S.) is indicated by the form of the hill and the trend of the large smooth surfaces of weathering, but is difficult to see on near inspection.

The acid type (sp. 23·48, sl. 7601) shows neither foliation nor porphyritic structure and is exactly like some of the Bairat granite, except that it has numerous clusters of tourmaline grains and no fluorite. There are many twisted lenticles of pinkish quartz (about one foot long and two inches thick as an average) containing a little feldspar and tourmaline; these are probably acid excretions¹ of a pegmatitic nature.

The central and northern hills (at Harsora) are composed of the micaceous type, well foliated and showing a foliation dip to the east. In all these hills there is a very distinct system of vertical joints running E. and W., and also bands, an inch or two thick, of highly micaceous, fine-grained material running in the same direction and presumably connected with the jointing.

In the smaller hills lying north of Harsora the Dadīkar rock is also seen, but unfoliated, forming great domes which weather in concentric shells, the curving surfaces being strewn with flattish loose blocks resembling enormous tiles. (Pl. 7, fig. 2.)

On the Harsora hill, above the village of Naror, are two large lenticles of extremely coarse hornblende rock, veined with quartz, and with a few feldspar crystals scattered through them. The larger is about twelve feet

¹ Harker, *Petrology*, p. 26, 3rd Ed.

in width. Surrounding them is a rim three or four feet wide of greasy yellow quartz, also containing a few feldspars. The junction of the hornblende and the quartz is highly irregular but absolutely sharp. Nothing abnormal was noticed in the adjacent granite.

If this were one of the feeders of the amphibolite sills, then its presence, traversing the granite, would of course prove that the granite had been intruded before the amphibolites, but I hesitate to accept this single instance as contradictory to the evidence which shows that the reverse order is the true one, especially when the occurrence is so exceptional, the hornblende in its extreme coarseness of grain and its freedom from disseminated quartz, being very different from the usual trap. Its peculiar characteristics of quartz veins and a wide rim of quartz, and with large but sparsely scattered feldspars, would indicate rather that it is of the nature of a basic segregation patch.

No sedimentary rocks are seen in contact with any part of the granite, but half a mile to the south of Ladpur Rock, separated from it by alluvium, is a crescentic broken ridge of Alwar quartzites dipping steeply away from the granite and running perpendicularly to the general strike of the ranges. The exposure lowest in the section is the small central hill, composed of regularly bedded and very micaceous quartzites, hard but splitting easily into flagstones. (Sp. 23·75, sl. 7624.)

It is noteworthy that similar flags are developed at Kirwari, at Todiar (near Dadikar) and at Basi, in all four instances near granite.

Near the junction of the Sabi and the Sota rivers at Pahari village, are two knolls of granite of both the acid and the basic types, finer than usual in grain and unfoliated. In the smaller hill the rock is a microgranite cubically jointed, in the basic variety of which the feldspars have weathered to epidote. No other rock outcrops anywhere near.

At Bajgiri (Baggeri and Bagheri of Hacket) are two exposures of the Dadikar type, well foliated, quite isolated amid alluvium.

N. E. of Khirtal is a considerable granite mass, of two types running in several bands in a S.S.W. direction (the same as that of the foliation) and shading into each other.

One kind is the micaceous Dadikar type, the other is quartzose and very hard and compact, medium in grain, unfoliated and non-

porphyritic. Examined under the microscope it is seen to contain much sphene and a small amount of greatly altered and corroded crystals of pale green pyroxene, also a little hornblende. (Sp. 23·50, sl. 7603.)

The smaller hills to the N.E. of this mass, near Tirwala, are of the Dadikar type, well foliated and veined with quartz. (Granites—sps. 22·350-1, sls. 6883-4, sps. 23·44-50, sls. 7597-7603.)

3. Pegmatites.

Little need be said about the pegmatites. They occur here and there at random throughout the area but never in any quantity, and can only be followed for a yard or two along their course. They are very coarse in grain, always unfoliated, and consist of pink orthoclase, quartz, muscovite and tourmaline, the last two never both being present in large amount. Quartz-tourmaline rocks are more frequently met with and are probably acid modifications from the same magma as the pegmatites.

Vein quartz may perhaps be the end-product of crystallisation, the last material to be extruded from the magma.

Those pegmatites to the south of Delhi have already been noticed, Rai Sina (p. 35), Kasumpur (p. 124), Arangpur (p. 125), Bhundsi (p. 36) and Kasan (p. 36), in all of which there is much muscovite and little or no tourmaline. The next towards the south is at Silarpur, where there are numerous thin veins of orthoclase-tourmaline pegmatite traversing the quartzite hill.

2½ miles N. of Khirtal, on the scarp above Kirwari village, are numerous veins of quartz, quartz with tourmaline, and quartz with muscovite, running like small sills along the bedding planes.

Forming the hanging-wall of one of the Kirwari flagstone quarries is a thick and coarse orthoclase-quartz-muscovite pegmatite with clusters of tourmaline. It yields a little kaolin, used by the villagers for whitewashing houses.

2½ miles N. E. of Hamirpur, where the road-cutting crosses the pass, is exposed a thick band of excessively coarse pegmatite of pink orthoclase, quartz, tourmaline and subordinate muscovite. (Sps. 23·51-2.) The feldspars are often as big as a man's head, and tourmaline crystals were seen a foot long and three inches diameter. The vein is about 15 feet thick, and is in contact with trap to the

west, quartzite intervening between it and a thinner trap band to the east. Approximately along the strike, near Titherpur, is a similar but finer pegmatite, also with trap against it to the west.

In the south are two occurrences, Bahtu and Pakher, both in the interrupted ridges of Alwars in the S.E. corner of the area, containing quartz, orthoclase, tourmaline and muscovite with a little apatite. (Sp. 22-359, sl. 6892.)

The former is finer and much more felspathic than the other. It forms several bands a foot or two wide, running chiefly along the bedding planes of the quartzites, but breaking across them and enclosing pieces torn off.

The latter, Pakher, is very coarse and is extremely rich in tourmaline. It forms a dyke about 15 feet wide.

Only two cases of pegmatite in the Ajabgarhs were noted in this area, one at the south end of the ridge at Mahanpur, where the phyllites are veined with quartz-muscovite rock, the other at Deotana, much weathered, with tourmaline in clusters; it contains long xenolithic strips of the grey quartzite of the ridge. In Torawati and Shekhawati the Ajabgarhs are extensively invaded by pegmatites.

Several of the more noteworthy cases of quartz-tourmaline and quartz veining have been described in the chapter on the Alwar Series (pp. 33, 36, 61, 67, 69, 83, 85).

CHAPTER X.

POST-TERTIARY FORMATIONS.

As is the case over so large a part of Peninsular India, we find that all the fossiliferous formations of the geological scale are absent and that nothing intervenes between the immensely ancient Purana rocks and the incoherent deposits which are being formed at the present day.

Talus-slopes, sometimes extending more than half-way up the hills, are prominent features of the quartzite and slate hills but are absent from those of limestone and granite, their absence in the former case being due to the solubility of the rock and in the latter to its forming under insolation a coarse sand which is readily washed down and distributed over the plain. The limestone and granite are very sparingly jointed and so do not break off in fragments, whereas the other rocks, the quartzites at least, readily give rise to angular debris, which disintegrates, with extreme slowness or hardly at all, into a sand fine enough to be removed by rain. The larger and more angular the debris the steeper is the slope of the scree, the maximum angle measured being 32° to the horizontal on a stable slope with bushes growing on it; for limited distances higher angles are attained.

The talus is not usually cemented by carbonate of lime and does not extend to any distance outwards from the foot of the hills, unlike the "bhábar" along the foot of the Himalayas and the "dháman" slopes of the north-west frontier hills.

The bottoms of the narrower valleys are covered by this coarse scree material, but where they widen out tongues of alluvium extend up them from the plains, between the talus slopes on either side.

This alluvium all belongs to the "bhángar" or Older Alluvium of the Indo-Gangetic plain, being in fact the extreme fringe of that formation.

It varies from a fine clay, the "loess" of Central Europe and the "pat" of Sind and the frontier districts, to wind-blown sand; though there is no sharp line of distinction between the varieties it may be conveniently divided into the three classes according to which revenue is assessed in the Alwar State, in order

of suitability for cultivation:—"chiknot" (clayey loam), "matyár" (sandy loam) and "bhúr" (sand).

Areas of all three may be found almost anywhere, but, generalising widely, one may say that "chiknot" is characteristic of the east and south-east of the area, "matyár" of the hilly parts and the centre, and "bhúr" of the north-west, a disposition roughly following the relative levels of the plain and connected with the distance from the semi-desert country of Marwar, the sandy country being on the average the highest, and the nearest to the Marwar plains, from whence much of the sand is wind-borne.

When uncultivated, "chiknot" forms a very smooth, hard plain, growing little grass, but covered with large clumps of the leafless green thorny "karíl" or "kair" bush (*Capparis aphylla*) and the "jhál" tree (*Salvadora persica*), the latter especially where the sub-soil water is somewhat salt, another salt-resisting tree being the tamarisk or "jhao" (*Tamarix* sp.).

It is the richest cultivated land, suitable for "juar" (giant millet) and cotton in the rains, and unirrigated barley and even wheat in the dry season, but owing to its occupying low land, *e.g.*, in much of Bharatpur State and Gurgaon and Muttra Districts, large areas are often flooded after a copious monsoon, with water which lies all through the cold weather, throwing good land out of cultivation and causing much malaria.

When thoroughly wetted it becomes almost semi-liquid, and to this is probably due the striking evenness of its surface, as any inequalities caused by wind erosion are promptly obliterated by the first heavy shower, which causes the surface soil, water-like, to "seek its own level."

"Matyár" is similar to "chiknot" but is more sandy, and covers the greater part of the area. Much the same crops are grown as on the latter, but it is more suitable for "bájra" (bullrush millet) than "juar" in the rains, and gram is more important as a cold-weather unirrigated crop than barley.

A common and characteristic plant on untilled "matyár" land is a dwarf jujube (*Zizyphus nummularia*), the leaves of which are greatly appreciated as fodder and the small hard fruit is eaten by the poor.

“ Bhúr ” forms slightly rolling country on which only “ bájra ”
 “ Bhúr.” can be grown in a favourable monsoon ; where
 it is flat enough for irrigation to be employed
 during the dry season, most irrigated crops can be grown, but un-
 irrigated are not successful.

Most of the “ bhúr ” remains fallow and supports large flocks of goats, sheep, camels and cattle, as its natural and peculiar flora is more abundant than that on more favoured land, since most of the rainfall soaks into the sandy surface instead of running off, and is subsequently available for the plants. Among the notable plants may be mentioned “ phóg ” (*Calligonum polygonoides*), “ khimp ” (a leafless green shrub with elongated conical pods), *Acacia jacquemonti*, and species of *Saccharum*, tussock grasses often ten or twelve feet high which are almost as useful as the bamboo, for from them is made rope and matting from the fibre of the leaves, and such articles as thatch, screens, corn-bins and chairs from the stems.

The richest soil of all, a grey calcareous clay somewhat resembling cotton-soil, is found in patches in some of the valleys where amphibolites outcrop.

Sandhills of the loose and shifting type are small and seldom
 Blown sand. met with in this area, and are practically
 confined to the east of some of the larger
 rivers, from the dry and sandy beds of which the sand is blown
 by the furious westerly winds of the hot weather.

Sandhills are of course abundant in the north-west, but a certain proportion of clay and the semi-desert vegetation which they carry bind the sand and prevent them from advancing. They are protected from rapid denudation by their porosity, for nearly all the rain falling on them sinks in. On the western side of such rock-ridges as have lying to the west of them a stretch of a few miles of open plain, a belt of sandhills is always found. The sand is heaped up against the windward (*i.e.*, west) side of these transverse barriers by the “ loo,” the hot west wind which blows with great violence and persistence during the warm months, when the plains are barest of vegetation and so in the most favourable condition to afford material for wind transport. The size of the sandhills accumulated bears a direct proportion to the area of uninterrupted plain over which the wind has blown before encountering the obstacle, and they are usually absent from all but the windward ridge, in places where several parallel ridges are near together.

Sometimes, where there is a saddle in a ridge, the sand has been blown over and collects to the leeward and, more rarely, an isolated patch of sand may be found high up on the leeside, near the summit of a ridge.

A deep trench is found between the zone of sandhills and the ridge, where the concentrated drainage from Increased rainfall. the latter has overcome the accumulative action of the wind, and the sandhills are cut up in all directions by narrow and tortuous ravines.

It would seem, judging from such indications as patches of sand high up on the hills and the deeply dissected sandhills to the windward of the ridges, that at the present day erosion is in the ascendancy over accumulation, and that the hills have been in the past much more deeply buried than they are now; everywhere in the neighbourhood of the hills the streams seem to be deepening their beds and markedly cutting back the higher portions of the alluvium.

The most obvious explanation of such a change would be that the rainfall, though even now by no means abundant, is greater than it has been in the past.

Two anthropological facts lend a certain slight support to this suggestion, one being the great rarity of weapons of the stone age in Rajputana as compared with other parts of India, and the other being that the traditions of many of the Rajput and Mina clans say that they came in from elsewhere. It may well be that in the days preceding the earliest traditions Rajputana was too arid for general habitation and that the influx of population, though no doubt due in part to pressure from outside caused by waves of Aryan immigration from the north, may also have been due to an increase in rainfall and consequent increase in fertility, which made colonisation feasible.

Nodular calcium carbonate, "kankar," occurs in great quantity near outcrops of calcite-yielding rocks—granite and limestones, and sometimes cements the boulders in stream-beds into a conglomeratic concrete.

Perhaps a few words on the flora may not be out of place. I have mentioned above some of the plants which are characteristic of certain types of soil. The commonest trees of the plains are the nīm (*Azadirachta indica*) and the babul (*Acacia arabica*), the latter being replaced

in sandy country by the "khejra" (*Prosopis spicigera*), which is much inferior to the babul as timber but is valuable as fodder for camels and goats, the leaves and pods being stripped and stored periodically.

The inevitable and unprofitable "ák" or "madár" (*Calotropis gigantea* or *procera*) is omnipresent. The larger trees do not form nearly such a prominent feature of the landscape as in the better-watered country near the Ganges and the Jumna, but near villages and wells there are usually pípal and banyan trees (*Ficus religiosa* and *bengalensis*), sometimes very fine specimens. Less frequent are the "gúlar" (*Ficus glomerata*), tamarind (*Tamarindus indica*), "sirís" (*Acacia lebbek*), "shísham" (*Dalbergia sissoo*), "bér" (*Zizyphus jujuba*), mango (*Mangifera indica*) and "jamun" (*Eugenia jambolana*), the last three being garden trees, grown with pomegranates and various species of *Citrus*.

The flora of the hills is totally different. Though the hillsides are excessively stony and seem bare of soil, they support quite a dense growth of low scrub in parts where they are protected, by forest regulations or by distance, from the depredations of fuel gatherers and goats. By far the dominant species of this scrub is the "dhao" (*Anogeissus pendula*) whose brown branches, leafless or with small and scanty purplish-brown leaves, give it a peculiarly dull and lifeless aspect. On the level tops of the hills this brown jungle is diversified with the bright green of "tendu" (*Diospyros melanoxylon* or *tomentosa*) and "sáler" (*Boswellia serrata*) trees.

The "dhák" or "palás" (*Butea frondosa*), the commonest tree in much of the Central India jungle, is found only in the bottoms of the damper valleys, such as the Siliberi Kho and round Kankwari, where strong grass grows and the trees are luxuriant enough to merit the name of forest, and where water stands perennially within a few feet of the surface, clumps of the wild date-palm (*Phoenix sylvestris*) show its presence.

Such common Central Indian trees as the teak (*Tectona grandis*) sál (*Shorea robusta*), silk cotton tree (*Bombax malabaricum*), mohwa (*Bassia latifolia*), and *Sterculia urens* are almost unknown.

The candelabrum-like Euphorbia (*E. nivulia*), known to the inhabitants as "thor," which flourishes all over Jaipur and Ajmer, is here only local, e.g., in the extreme south of the area and near the Siliser Lake. Where it occurs it is in great abundance. A notable peculiarity of this Euphorbia is that it never grows except on rocky ground; where the scree-slopes meet the alluvium the Euphorbia abruptly ceases.

CHAPTER XI.

NOMENCLATURE AND CORRELATION.

The chief difficulty in describing this area has been the confusion caused by Hacket's reversal of the succession in his second paper, and it was in order to find the correct interpretation that the resurvey was undertaken.

The net result of my detailed examination, not only of this area but of all Rajputana north of latitude 26° and east of longitude 75° , including the sections on which Hacket based his subsequent change of view, is that I go back to Hacket's original opinions. (See Table, p. 106.) His first paper, though far too short to present an adequate account of such a large and complicated area, is, except for his omission of the intrusives in the Delhis, an excellent epitome of the geology; and I would here again express my sense of admiration of his work and great indebtedness to him as the pioneer, upon whose foundations I have been enabled to build. In revising another's work one is inclined to dwell little on the points on which there is mutual agreement and to pay more attention, no doubt naturally and unavoidably, to matters on which one's own opinions are not at one with his, so bringing into undue prominence in the reader's mind the points at variance.

It is therefore to be remembered that although I strongly disagree with much of Hacket's later work and with the conclusions set forth in his second paper, my survey corroborates almost everything in the first paper. Had the second paper remained unwritten the geology of Rajputana would not have fallen into the confusion from which I am now endeavouring to extricate it; amplifications would have had to be made, but few corrections, except in the case of the igneous intrusives.

In Hacket's second paper¹ he removes the Ajabgarh (and the Mandan) Series from the top of the upper system and correlates them with the Raialos at its base. He then classes them both with the "Schist series"—the lower system of the first paper—and separates the Alwar quartzites to form the new "Delhi Series," or, put in

¹ *Rec., Geol. Surv. India*, XIV, pt. 4, p. 281.

Table of comparison between Hackett's two classifications and that now adopted.

| Hackett, Rec., Geol. Surv. India, X, pt. 2. | Hackett, Rec., Geol. Surv. India, XIV, pt. 4, and "Manual of the Geology of India." | Present classification. |
|--|---|---|
| <div>Aravalli Series.</div> <div> <div>Mandan Group . . . F</div> <div>Ajabgarh Group . . . F</div> <div>Limestone (Kushalgarh) . . . E</div> <div> <div>Alwar Group.</div> <div> <div>{ Alwar quartzites . . . D</div> <div>Raialo limestone and quartzite . . . C</div> </div> </div> </div> | <div>Delhi Series. { Alwar quartzites, D and part of F.</div> <div>....</div> | <div>Delhi System.</div> <div> <div>Ajabgarh Series . . . F</div> <div>Kushalgarh limestone (local). . . E</div> <div>Alwar Series . . . D</div> <div>Raialo limestone and quartzite (local) . . . C</div> <div>Unconformity.</div> </div> <div>G Granites intrusive in Delhi system.</div> |
| <div>Schist Series A</div> <div>Gneiss B</div> | <div>Aravalli { A, C, E, and F, part of D.</div> <div>Gneiss . . . B and G.</div> | <div>Aravalli System.</div> <div>(Undivided) . . . A</div> <div>B Granites intrusive in Aravalli system.</div> |

another way, he denudes the upper system of everything but the Alwar quartzites, renames it the "Delhi Series" and includes in the lower system what has been taken away, carrying down the name 'Aravalli' from the upper system to designate the lower.

I have explained above (pp. 23-25) how the Raialo limestone is separated from the lower system by a great unconformity and passes conformably into the Alwar quartzites, and so cannot be put into a different system from them. It is also quite unlike anything seen in the lower system, in which limestones are very rare.

To correlate the Raialo limestone with the Ajabgarhs is still more unthinkable, the one being a pure white saccharoidal dolomite, the other a congeries of slates and impure quartzites, with, it is true, a limestone at its base of about the same thickness as the Raialo, but one which is entirely different, being a siliceous, non-dolomitic, fine-grained rock, conspicuously banded in grey and black, so that they are about as unlike as two limestones could be. I can imagine no possibility of their being variations of the same rock, for outcrops of each are seen not far apart all over the south of the area, each maintaining its own characters and its dissimilarity from the other. For instance, taking an E.-W. section along, say, latitude $27^{\circ} 10'$, Ajabgarhs are seen in the Partabgarh valley, the Raialos near Kaler a little distance south of the line of section, then comes the Ajabgarh valley, the Raialos of Baldeogarh, and the Ajabgarhs of the Deoti Lake.

It is of course impossible that such a periodic alteration of lithological characters in a lateral direction, as would be necessary on Hackett's interpretation, could have taken place.

Moreover, there are several sections, both normal and inverted, so clear as to obviate any chance of error, in which the Alwar quartzites are seen to lie above the Raialo and below the Kushalgarh limestones, *e.g.*, those south of Kudha-Mingi and east of Burjo, which are normal, and the inverted section east of Jhiri.

Much the same arguments apply to the correlation of the Ajabgarhs with the lower, pre-Delhi or Aravalli system; the sections just cited show quite clearly how the lower system is separated from the Ajabgarhs by the great unconformity and by the Raialo limestone (when present), the Alwar Series and the Kushalgarh limestone.

There is in this case the excuse that the two formations correlated have a strong lithological resemblance to each other, both being associations of argillaceous rocks with subordinate zones of thin

quartzites. The lower system is in general more metamorphosed and much more invaded by igneous rocks than the Ajabgarhs, but the likeness is such that the classification of isolated outcrops cannot in many cases be made without relying on their general field relationships.

Hacket, in the map accompanying his second paper, has pushed the consequences of this correlation to an extreme in the ridges in the east of the Alwar State and in the south of Jaipur, mapping argillaceous beds as Aravallis (the lower system) and the interbedded quartzites as Delhis, quite irrespective of their clear conformity; he has also coloured the Raialo quartzites as Delhi (and the limestone as Aravalli). This is more clearly seen in many of his detailed maps (1 inch=1 mile), where, by colouring quartzite ridges as Delhi and valleys formed along the outcrops of argillaceous, micaceous and calcareous beds as Aravalli, an arrangement which hardly seems to accord with their apparent field relations, he has produced a map which is lithological rather than geological.

So far as I have been able to ascertain, he changed his views on the order of the succession without revisiting the area which led him to form his earlier and correct opinion. He states (*loc. cit.*) that "Upon further examination of the series in the country to the west, where the sections are less broken, I found that this was not the true interpretation of the section, but that both these groups (*i.e.*, Ajabgarh and Mandan) were below the (Alwar) quartzites in fact representatives of the Raialo group. I was led into this error by the high dips of the rocks and by taking inversion for the normal sequence." As I have shown above, the same sequence is given by inverted as by normal sections, and even the country to the west, all of which I have examined, shows equally clearly that the Ajabgarhs overlie the Alwars.

The nomenclature of the two systems has been a source of considerable difficulty to me. Hacket's names for Nomenclature. the various groups are very appropriate, and so also is the term 'Arávalli'¹ for the upper division including the Raialos, Alwars, the Kushalgarh limestone and the Ajabgarhs, being the designation in ancient Hindu literature and in modern

¹ Other modes of spelling the word are 'Arvali' and 'Arvalli,' but 'Arávalli' is that usually accepted at the present day. It has been variously derived from 'arbali' a Hindi or Sanskrit word said to mean 'higgledy-piggledy,' applied to any broken ground (*Archaeological Survey Reports*, Vol. XX), and from 'ára'—a saw, in allusion to the serrate nature of the range, a feature which is not conspicuous in the Alwar country.

geography of the mountainous tract of Rajputana which extends from the plains of Gujarat to Delhi and forms one of the most prominent topographical features of Peninsular India.

The introduction of the name 'Delhi' has been unfortunate. Not only is the Delhi System poorly exposed at Delhi, which lies at the extreme northern limit of the area occupied by the system, but in using it we have the anomaly that the Aravalli mountains, as far as I have followed the range southwards, are made up chiefly of rocks belonging to the Delhi system, while the Aravalli system forms the plain country to the south-east, with, it is true, a few ridges, some of considerable height, running parallel to the main range through the centre of the plain in Jaipur and Tonk.

Another awkward circumstance is that my 'Delhi System' is exactly equivalent to the 'Aravalli Series' of Hacket's first paper (see Table, p. 106). Had I been free to do so, I should have preferred to discard 'Delhi' and go back to Hacket's original name as well as to his original classification, and so call the upper system 'Aravalli.' A new term could then have been adopted to include the "Schist Series" of his first paper and the other allied rocks of the lower system, below the unconformity. I could hardly do this, for the names were introduced by Hacket and I am not in favour of setting aside more of the original investigator's work than truth demands.

I have been forced to alter greatly his distribution of the various series among the two systems according to his second paper, but the main point of my classification remains the same as his, namely, the recognition of two great systems separated by an unconformity.

The terms 'Delhi' and 'Aravalli' have been fixed in Indian geological nomenclature by their use in the "Manual of the Geology of India" (pp. 67—72) and elsewhere, the latter as one of the local synonyms for the Dharwar,¹ very probably correctly, judging from their close resemblance. It would cause considerable confusion to transfer the designation 'Aravalli,' which is well established as meaning an assemblage of rocks of the Dharwar type, and possibly also age, back to a system which has no resemblance to the Dharwar and is almost certainly much younger.

After all a name is merely a name, and it is better to retain one which has passed into use, even though incorrect in its derivation, than to transfer it in favour of a geographically correct term, with the

¹ Vredenburg, "Summary of the Geology of India," p. 17; Fermor, *Mem., Geol. Surv. India*, XXXVII, pt. 2, p. 237.

risk of causing misapprehension owing to its having heretofore been used in a different sense.

The correlation of these two rock-systems with rocks in other parts of India is attended with difficulties and uncertainties, and it would be unwise, in the present state of our knowledge of the Archæan and Precambrian groups, to attempt anything more than a tentative correlation, based on general similarities and without the precision attainable in fossiliferous rocks.

We may, I think, say with certainty that the Aravallis are Archæan, and that they resemble in type the Dharwars of central and southern India rather than the underlying gneisses, without pushing the analogy so far as to state that they are strictly contemporaneous. The presence of conglomerates in the Aravallis indicates that unconformities are present and that more than one series may be included (as is probably the case in the Dharwars), but the exposures are too fragmentary to yield definite evidence of this, or even to prove beyond a doubt that the conglomerates are epiclastic and not autoclastic.

The post-Aravalli unconformity probably, as I have suggested (p. 11), represents the Eparchæan Unconformity of North American geologists.

The Delhi System would seem to be a thing apart in the Peninsular post-Archæan formations, both in its intense folding and in the amount of its igneous intrusives. Its general facies¹ is that of the Cuddapah system, or rather any one of the sub-divisions of the Cuddapahs, in that it consists of quartzites in its lower portion, passing upwards into slates, as is the case in each of the four divisions² into which the Cuddapahs have been divided.

Its thickness too, is comparable with that of the entire Cuddapah system, 20,000 feet, and other resemblances are the mutual possession of intrusive and contemporaneous trap and of several unconformities, though in the case of the Delhi system these breaks are local and are properly seen only in the Biana hills outside the present area. Here the similarity ceases, and it would be unwise to correlate two areas so very widely separated on such general resemblances. The Cuddapahs are, as a whole, moderately inclined at angles of dip

¹ Its nearest analogue is possibly the Champāner beds (Manual, p. 73), but little is known about them.

² *Mem., Geol. Surv. India*, VIII, pt. 1, p. 126.

which are much lower than those usually met with in the Delhis, and it is only in a narrow belt along their eastern margin that they assume the steep plications and inversion which are almost universal in our area.

Granite and pegmatite intrusions are quite absent from the Cuddapahs, as they are from all the post-Archæan rocks of Peninsular India, with the exception of the Delhis and the Malani rhyolites of Western Rajputana,¹ in which latter the Siwana and Jalor granites are intrusive.

The Delhi System bears no resemblance to any of the other Purana systems of India, such as the Bijawars or the Vindhya.

Taking it to be post-Dharwar, which I think may be considered fairly certain, we have two alternative explanations of its more folded and altered condition as compared with the other Purana rocks.

The Delhis may be much older than the Bijawars and the Cuddapahs, though still post-Archæan (post-Dharwar), and may have no equivalents in the Peninsula, representing a time when deposition was in progress to the north of the Archæan shield of Peninsular India, while the rest of the shield was still dry land on which the Cuddapahs, etc., were subsequently to be accumulated.

Judging from their profound plication and the abundance of their intrusive igneous masses, they have been more involved in mountain-forming earth-movements than the other Puranas, *e.g.*, the Cuddapahs, but not to the same extent as the Dharwars.

There is no reason to believe that the disturbances which infolded the Dharwar synclines into the crystalline complex ceased abruptly; they may quite well have continued, with ever diminishing intensity, through the period in which the Delhis were folded, affecting in their final manifestations even the younger Puranas and producing the gentle basin-folding of the Cuddapahs and the Vindhya.

The other alternative is that the Delhis are roughly contemporaneous with the Cuddapahs or the Bijawars, *i.e.*, are among the older Puranas but are not necessarily the oldest, and that they owe their folding and the related intrusion of granite batholiths to a special local upheaval in Rajputana which did not affect the rest of India, or to a local persistence of disturbance in Rajputana after it had almost died out elsewhere.

¹ La Touche, *Mem., Geol. Surv. India*, XXXV, pt. 1, p. 24.

In the first alternative we suppose that the Delhis preserve part of the evidence for a general continuance of folding affecting all the Puranas with decreasing intensity according to their age, evidence which is not elsewhere obtainable since they are (supposedly) the only representative of the earliest Purana times; in the second case the Delhis are presumed to have their approximate equivalents in other parts of the Peninsula, but to have been folded in this particular area alone by movements which were absent or insignificant elsewhere. The latter is, I think, more probable.

The Aravalli range is alone among the mountain-ranges of the Peninsula in being composed of folded rocks, with the axes of disturbance corresponding with the direction of the ridges. Not one of the other great mountain chains is anything but a plateau, or portion of a plateau which has escaped denudation, either of nearly horizontal rocks or of crystallines in which the strike has only a local connection with the direction of the hills.¹

In the metamorphic areas there are many instances of the roots and relics of ancient mountain systems, but, with insignificant exceptions, all have been worn down to undulating plains or plateaux. What is more natural than to infer that the Aravalli chain owes its prominence partly to its belonging to a later stage of uplift than the vanished mountains now occupied by the metamorphic plains?

Oldham has suggested that the period of upheaval of the range may be as late as Upper Vindhyan; I quote the passage.² "The north-western boundary of the Vindhyan is in the main a fault of great throw, along which the almost horizontal Bhandar sandstone is brought into contact with the highly disturbed Aravalli beds. Beyond this fault, there are a few small, but important outliers, composed of the lower members of the system.

The throw of this fault must be at least 5,000 feet, and there is naturally some difficulty in accounting for a single fault of so great a throw having been formed subsequent to the deposition of the Vindhyan, and among beds which have undergone so little subsequent disturbance as they have.

But we will find when treating of the Himálayas that the nature of the boundary between the Vindhyan and the disturbed Aravalli

¹ *Manual, Geology of India*, pp. 4—6.

² *Manual, Geology of India*, p. 103.

beds is very similar to what we may infer is the contact between the undisturbed deposits of the Indo-Gangetic plain and the disturbed beds of the Himálayas. Moreover, along the foot of the Himálayas, there is a strip of upper tertiary beds which have been disturbed, but to a less degree than the older beds of the range, while the equivalents of these beds are believed to occur under the alluvial plain, in perfectly conformable sequence with the most recent alluvium.

Now, if these suppositions are correct, as is almost certainly the case, we can imagine that, after ages of denudation, the upper tertiary rocks of the Siwalik zone will be almost removed, and the northern boundary, of what is now known as the Indo-Gangetic alluvium, will then exhibit very much the same features as the boundary of the Vindhyan towards the Arávalli range now does.

The upper beds will be in contact with highly disturbed rocks of much more ancient date along a great line of fault. Beyond this will be a few outliers composed of the lower beds of the series, the Siwaliks of the present classification, and to the north of these there will be a broad exposure of the wreck of a mountain range.

In the case of the Himálayas the fault has been gradually formed *pari passu* with the deposition of the Indo-Gangetic alluvium which is contemporaneous in its origin with the principal elevation of the Himálayas and formed of the débris of that range.

It is natural to suppose that the similar structure in the case of the Arávalis indicates a similarity of origin, and that the great Vindhyan spread of Central India is formed of deposits which bore the same relation to that range as the Indo-Gangetic alluvium does to the Himálayas.

The suggestion is an important one since it would fix the period of the formation of the Arávalli range, or at any rate of its principal importance, as contemporaneous with the deposition of the Upper Vindhyan rocks that were formed of its débris."

It is quite likely that there was a close connection between the upheaval of the Arávalli range and the outpouring of the Malani rhyolites¹ west of it; they are most probably the effusive lavas the magmatic stocks of which are the batholithic granites intrusive in the Delhis.

Effusion of Malani
rhyolites.

¹ La Touche *Mem., Geol. Surv. India*, XXXV, pt. 1, pp. 19—24.

These lavas and associated rocks cover an immense area, 145 miles from east to west and 120 miles from north to south, and are found far beyond this tract, projecting from the alluvium in the Shekhawati country in Jaipur, at Tusham¹ hill in the Southern Punjab, and in the Kirana² hills, only 40 miles from the Salt Range, in the Talchir boulder-bed of which their fragments occur.

Their wide extent—for such acid lavas are rarely fluid and wide-spreading—the absence of any concentric arrangement of the sheets, such as would be expected if they had been ejected from a centre or centres of eruption, and the absence of any pipes, all tend to prove that they were the product of fissure eruptions rather than volcanoes of the Vesuvian type, and it is a reasonable suggestion that these fissure eruptions inaugurated the uprising of the Arávalli chain. Their precise age is not certain, but they are known to rest with a violent unconformity on slates or schists of Aravalli age, and were subjected to a long period of erosion and weathering before the upper Vindhyan sandstones were deposited on them. If contemporaneous with the Lower Vindhyan, or what is more probable, with the uppermost Delhis—for in the Kirana hills they are interbedded with sedimentaries of Ajabgarh type—their age would be quite consistent with Oldham's suggestion that the Aravalli mountains arose during the deposition of the Upper Vindhyan.

The Erinpura granite of La Touche³ is, I believe, the same as the granites intrusive in the Delhi system in this area. I have not seen it at Erinpura, but have examined it near Abu, which is in continuation of the Erinpura mass, and find it the same as the granites at Bairat, Harsora, etc.

On the map accompanying his memoir La Touche has coloured the schists and quartzites in which it is intrusive as Arávalli, but refers to them in the text (p. 16) as Delhis. The latter diagnosis is probably correct with regard to the rocks in the main range, which appear to continue the Delhis of the Ajmer District along the strike; the exposures on the plain to the west of the hills may belong to either system.

The Jalor and Siwana granites of La Touche, intrusive in the Malani volcanic series, are not represented in my area, nor are the basic olivine-dolerite dykes.

¹ McMahon, *Rec., Geol. Surv. India*, XVII, pt. 3, p. 101; XIX, pt. 3, p. 101.

² Heron, *Rec., Geol. Surv. India*, XLIII, pt. 3, p. 229.

³ *Mem., Geol. Surv. India*, XXXV, pt. 1, pp. 16, 18.

The existence of intrusive granites in the Delhis may be remarked on, for the reason that they are absent from the other Purana systems in the Peninsula, and are only doubtfully present in the related Algonkian (Keweenaw and Animikie) of North America, but their presence is no argument for placing the Delhis in the Archæan.

Granites may occur in rocks of any age, depending on local tectonic conditions; it would be as illogical to separate the Eocene of Burma from that of Baluchistan, because the latter is invaded by granites while the former is not, as to argue that the Delhis must be of Archæan age since granites are not found in other areas of Indian Purana rocks.

We know that granites intrude the Malani volcanic series, which no one considers to be other than a post-Archæan formation, and though there is some doubt regarding their presence in the Algonkian of North America, they occur in the Kalevian and other groups of Fennoscandia of supposed Algonkian age.

In case the possibility that the Delhis are of Dharwar (Huronian) age may have occurred to the reader, I may in conclusion mention my reasons, other than those already given, for thinking this most improbable.

Delhis not Dharwarian.

The great development of massive quartzites in the Delhi system has no counterpart in any of the Dharwar or older Archæan areas, whereas the facies of the underlying Aravallis is distinctly that of the Dharwars.

If the Delhis were Dharwarian in age, the Aravallis would belong to the older gneisses, and we should expect that the unconformity would display those dubious and uncertain features which render the relationship of the Dharwars to the older gneisses so difficult to decipher.

The unconformity between the Dharwars and the basement complex in some cases was taken for granted at a time when it was thought that all rocks of apparently sedimentary origin must necessarily have been laid down on the worn surface of the basement complex. Conglomerates, some of them now known to be crush products, seldom or never occur at the base of a Dharwar section.¹ There is here no dubiety; the unconformity between the two systems has the clear character of that between, for example, the basal Cuddapahs and the Dharwar synclines or the gneissic series.

¹ Holland, "Archæan and Purana Groups of Peninsular India," *XIIe Session Internal Geol. Congress.*

In dealing with separated areas of metamorphic rocks precise correlations often cannot, and certainly cannot always, be made, and all that can be done is to rely on general resemblances and the balance of probabilities, always keeping in mind that such correlations have not the certainty achieved by fossil evidence and are liable to revision as the knowledge of allied areas accumulates.

CHAPTER XII.

ECONOMIC GEOLOGY.

There is a full account of the mineral resources of Alwar State in the Mining Journal for 1884, p. 1029, by T. F. Andresen, M.E., and some notes are given in Major P. W. Powlett's Gazetteer of Ulwar, 1878, as well as in Hacket's paper¹ on the "Useful Minerals of the Arvali Region" which treats of the British districts and Bharatpur State as well. Various references are to be found in the Punjab Gazetteers and other Government reports.

As in so many other parts of India where mining has formerly existed, all activity is now extinct, through exhaustion of ore, scarcity of fuel, competition of imported materials or even discouragement by the authorities of the States, and now only ruined workings and dim traditions remain.

Iron.

In 1873 there were thirty iron-smelting furnaces at work in Alwar State, producing 536 tons per annum, chiefly at Rajgarh, Tehla and Baleta, now, however, entirely extinct. Statistics of the industry are given by Major Cadell in Powlett's Gazetteer, as also are details of the copper workings at Daribo near Kho, and prices of the various building stones at that date.

At many places where it is specially ferruginous, small pits have been dug in the hornstone breccia. The chief of these are in the ridge 1 mile E.S.E. of Kushalgarh. They are said to have been worked for copper, but as I could not find the faintest trace of copper ore near them and as the breccia is here very rich in iron, I am inclined to think that they were sunk for the latter.

I have mentioned above (p. 28) the irregular masses of highly ferruginous material in the Raialo limestone near Raialo and Nimla, which I consider to be due in all probability to metasomatic replacement of the calcite by iron oxide.

¹ *Rec., Geol. Surv. India*, XIII, pt. 4

Whenever a hillock is seen in the Raialo limestone it is found to be due to the superior resistance to denudation of these masses, which stand out as dark-coloured piles of rock from the level stony plain of yellow or pale brown weathered limestone. The rock varies according to the amount of replacement, from marble stained brown by iron to nearly pure hematite. The deposits are elongated more or less in the direction of the strike, but thicken and thin out in a quite irregular manner; they are in fact lines of irregular lenticular masses rather than bands.

It is difficult to estimate their real thickness, as the slopes are covered with boulders, which are strewn to a great distance around and give an appearance of thickness greater than the reality.

These are all within Jaipur State and so far have not been mentioned in any publication, though they are the only sources of iron-ore in this area likely to be of any economic importance.

The largest deposit forms a ridge a mile long, about half a mile east of Nimla. This has been extensively worked in the distant past but the ore extracted is only a fraction of what still remains. Bands up to seven or eight feet across, seemingly pure hematite, were measured, and there are many still wider. If thin calcareous layers, which would be mined along with the ore and eliminated by hand-picking, are included the width must run to many yards. To thoroughly prospect and estimate the available ore would require a great deal of labour in the removal of the thick mantle of detached blocks, not to mention the clearing of the low but dense and thorny jungle. There is certainly an enormous amount of ore.

So far a full analysis is not available,¹ but if free from detrimental impurities it should become a valuable property, if a general demand for iron-ore ever arises in India. The nearest railway station, Dosa, is 15 miles distant, the intervening country presenting no impediment to railway or tramway construction.

¹ A partial analysis done in the laboratory of the Geological Survey of India, from an average piece, gave—

| | | | | | | |
|--------------------------------|---|---|---|---|-------|--------|
| Fe ₂ O ₃ | . | . | . | . | . | 91.54 |
| Al ₂ O ₃ | . | . | . | . | . | 8.46 |
| | | | | | | <hr/> |
| | | | | | TOTAL | 100.00 |

Phosphorous a trace.
No sulphur.

The mines of Rajgarh are large open workings in two small hills 1 mile S.E. of the town, in a brecciated limestone (probably of pre-Delhi age), the calcite of which has been replaced by limonite. Where limonite is not present the rock is seen to be a fairly white crystalline marble. Much of the ore has been left as a cellular mass by solution of the calcite. The hill has been quarried to below ground-level, trouble with water ensuing, and laterally as far as the quality of the ore paid.

These mines are said to have produced much of the raw material for the furnaces at Rajgarh, Tehla and Baleta, but they ceased working long before the iron-smelting industry stopped, the ore latterly probably having come from other mines, *e.g.*, Bhangarh.

"Mr. Andresen has ascertained that this large deposit of iron ore extends in a regular belt for a distance of over $1\frac{1}{2}$ miles in length, and has an average width of 500 feet; that it has been followed to a depth of over 120 feet; that it consists chiefly of rich red and brown hematites, specular iron; and that it is notably devoid of the presence of foreign minerals.¹"

A similar rock forms hills on both sides of the railway line at Jaisingpura, about 2 miles N.E. of Baswa. In this there is also magnetite and earthy manganese ore.

Ancient workings of a micaceous hematite schist in the Alwar quartzites are seen in a ravine 3 miles north of Tehla. The richest bed seems to have been worked out; I could find nothing *in situ* to compare in quality with some of the scattered fragments. There is no local tradition of the working of this ore-body (sp. 23"114, sl. 7653).

The mines of Bhangarh, 2 miles N.E. of the ruined and deserted town, a former capital of the Rajawat Rajputs, were still worked at the time of Hacket's visit, but are now disused.

They are large open workings on the crest of a hill, with short irregular adits, and are several hundred yards long, and in places twenty or thirty yards wide. It is evident that an enormous quantity of ore has been taken from them.

The ore consisted of a mixture of limonite, magnetite and oxide of manganese, a sample analysed by Mallet containing 59.67 per cent iron and 12.7 per cent manganese.² What ore remains is very light

¹ *Mining Journal*, 30th August 1884, p. 1029.

² *Rec., Geol. Surv. India*, XIII, p. 248.

and earthy and would appear to be an impregnation and replacement of the Raialo limestone and some slaty beds of the Alwars, here brought into contact by a fault which has probably given access to the mineralisers (sp. 23'118).

The iron ores of Firozpur in Gurgaon (and the methods of smelting them) were described eighty years ago by Captain Boileau,¹ but are of no value.

They occur in the Alwar Series and are similar to those of Bhangarh and Rajgarh—brown earthy limonite.

Manganese.

The occurrence of oxide of manganese in the Bhangarh iron ore has been referred to above, and I observed small masses of it at several places, *e.g.*, Akbarpur, in the ferruginous matrix of the hornstone breccia, and in the crystalline limestone hills at Jaisingpura.

Gold.

Hacket² records that after the rains the villagers of Sohna in Gurgaon used to get small quantities of gold at the foot of the hill, presumably washed out of the Alwar Series.

Diligent enquiry on my part was ineffective in bringing to light more than a tradition that gold had been found in the past. The name of the village is an archaic word meaning 'beautiful,' referring to its situation, and is not connected with the Hindi word for gold—*sona*.

Nickel.

Traces of nickel are recorded by Hacket from the Bhangarh ore, and from iron made into cannon balls, which flew into pieces when fired, smelted from this ore.³

Copper.

The most important workings are those of Daribo (near Kho), vertical shafts along a ridge on an anticline near the base of the Alwar Series; the ore, chalcopyrite, with pyrrhotite and perhaps arseno-pyrite, occurs irregularly disseminated through a band of slates (sp. 23'115).

¹ *Gleanings in Science*, Vol. III, p. 327.

² *Rec., Geol. Surv. India*, XIII, p. 249.

³ *Rec., Geol. Surv. India*, X, p. 92.

and is almost absent from the quartzite above. It is certainly not a lode, though Andresen says that the deposit "is a true fissure vein, occurring at the junction of the quartzites with the black slates, the copper-bearing stratum being formed between these. The hanging wall consists of quartzite and the foot wall of black slates. The course of the lode is a few points east of south, with an average width of 20 inches; the cropings can be plainly traced for a distance of over half a mile, and the ledge has a varying dip of from 80° to 50°. The mineral is principally copper pyrites.* * * * The Chipta copper mines, of which there are two, are situated in a series of rolling hills about 4 miles from Dariba; they are said to have yielded good ore in large quantities."

A full account, by Major Cadell, of the methods of smelting, is given in Powlett's Gazetteer of Ulwar. At the time of Hacket's visit in the seventies mining had almost ceased, but alum and ferrous and copper sulphates were still manufactured from the water and the efflorescence of the mine—now all is stopped.

The great heaps of débris and slag show the former extent of the industry, but now very little ore is to be seen, and that mainly as a green basic carbonate incrustation in joints.

Hacket records traces of copper on the same geological horizon $1\frac{1}{2}$ miles west of Daribo.¹

The copper mines of Bhangarh are immediately S. of the iron mines, a number of vertical pits sunk in a brecciated siliceous band at the top of the Raialo limestone. No ore was seen *in situ* but numerous pieces lie about on the dump-heaps.

Kushalgarh. The Kushalgarh workings, said to be for copper, are mentioned above (page 117).

Those of Partabgarh are four miles to the S.W. of the village, numerous deep shafts sunk vertically along the strike, at the top of a quartzite ridge, and a huge trench running across it at an angle. The latter is rumoured to have been opened by a rock-slide. The workings were in the trench also, and are said to have partly collapsed in a subsequent slip, burying many miners. I was unable to find a single piece of ore. The ruins of houses in the valley below indicate a former large population, and the slag-heaps are extensive. These

¹ *Rec., Geol. Surv. India*, XIII, p. 243.

mines ceased producing before the days of Partab Singh, the founder of the Alwar State, who flourished in the latter half of the eighteenth century.

Slight indications of copper were seen by Hacket at Tasing¹ and Jaisingpura¹ (near Baswa) and by myself at Hamirpur, Guda, Judawas (Indawas¹ of Hacket), and Nabaro and Udhala, two villages N.W. and S.W. of Sainthal; at the last mentioned localities small prospecting pits have been sunk.

Lead and Silver.

At Judawas there are two long open cuttings, 20 to 30 feet deep, sunk in two parallel bands of creamy granular quartzite in the impure limestones of the Ajabgarh Series. They are filled with water and débris, so no ore was seen *in situ*.

In the Ulwar Gazetteer² (Powlett) it is stated that the mines had been reopened, and that the ore, galena, was found to contain 1 per cent silver and 80 per cent lead.

The name of this locality is misprinted 'Indawas' in Hacket's account.³

I was unable to find any galena whatsoever, but on the spoil heaps around are quantities of rock, quartzite (sp. 23-120) with grains of copper ore disseminated through it. On the one inch Survey map the locality is marked "Copper Mines."

Hacket states that "a few years ago a small deposit of silver-lead ore was discovered in the Kushalgarh limestone near Gudha (Guda) and a pit was sunk in it; but after working for a short time it was found that the ore died out in every direction."⁴

There is no Kushalgarh limestone in Guda village boundaries, but 1½ miles S.E. of Guda, where the impure Ajabgarh limestones are copiously injected with thick quartz veins, four or five of these veins have been taken out as trenches 10 to 20 yards long, 10 feet deep and 5 to 15 feet wide. In the fragments of quartz lying about there are numerous grains of cuprite altering to malachite.

¹ *Rec., Geol. Surv. India*, XIII, p. 244.

² Page 83.

³ *Rec., Geol. Surv. India*, XIII, p. 248.

⁴ *Rec., Geol. Surv. India*, X, p. 91.

Graphite.

In a small ravine just south of Sohna there is exposed among the Alwar quartzites a band of schist (sp. 24"638) in which are at least two layers rich in graphite, the eastern some six inches thick and the western three to four feet. Both are much covered along the strike by débris. The graphite is in small irregular lenticles in arenaceous and micaceous stuff, and is very impure. It was first reported on by Dr. W. J. Thomson, Civil Surgeon of Gurgaon, in 1861, and some pencils were actually made from it. After considerable attention from Government, the matter seems to have been dropped on Dr. Thomson's death. Hackett¹ describes the deposit as worthless, an opinion in which I concur. There is too little and it is too impure to be of any value.

In many places the Ajabgarh slates are notably graphitic, staining the fingers when handled. A black slate, probably similar, is quarried in Kishengarh State and manufactured into paint, chiefly for railway purposes.

Asbestos.

Amphibole asbestos occurs at two localities, in the Kushalgarh limestone near Delawas, and in the Ajabgarh argillaceous limestones N.W. of Guda; in both cases the containing rock is much injected with vein quartz. The asbestos is a local modification of the bladed tremolite so common in these rocks, and forms "pockets" of radiating needles, irregular in size and shape, scattered at random through the limestone (Sps. 22:317 and 22:319, sls. 6856 and 6858).

At the former place, 2 miles due N. of Delawas, it is in large quantity, but being in rather short and stiff fibres, is unlikely to be of any use for textile purposes.

Amphibole asbestos is weaker and less flexible than chrysotile asbestos, but is more refractory. Its market price is considerably lower.²

Rutile.

Rutile is reported by Mallet³ as occurring in small quartz veins in the Motidongri hill near Alwar City. This is now occupied by a palace and I was unable to examine the locality.

¹ *Rec., Geol. Surv. India*, XIII, p. 249.

² *Bulletin of the Imperial Institute*, Vol. III, p. 277; F. Cirkel, "Asbestos," *Canada Mines Dept.*

³ *Rec., Geol. Surv. India*, XIII, p. 249.

Kaolin and mica.

These are extracted in small quantities for house and pottery decoration from many of the pegmatite veins
 Uses. in the Alwar Series.

"A fine specimen of mica in large plates," from the Gurgaon District, was exhibited at the Lahore Exhibition of 1864,¹ but I have not seen any from the present area which would be of the slightest value for industrial purposes. Mica is used locally for a number of minor purposes, *e.g.*, it is mixed with red powder and thrown about during the Holi celebrations, and is cut into discs which are sewn on women's dresses, as well as for house and pottery decoration.

The only kaolin occurrence of any importance is at Kasumpur (Kasumbi) 8 miles S.W. of Delhi, and at two places a mile to the south of Kasumpur, in pegmatite veins in the quartzites (sp. 24·630).

During the rains the soft material, consisting of quartz, mica and orthoclase, is washed by hand in basins
 Method of washing. standing on the edge of small square tanks, into which the water containing kaolin and fine particles of mica in suspension is thrown, leaving the coarser material, quartz and most of the mica, in the basins. After settling, the water is drawn off or evaporated. The layer of kaolin (about 3 inches thick) at the bottom is either allowed to harden and is cut into blocks about 10 inches square, or is taken out when pasty and formed into flat circular cones 3 inches in diameter. The first form is sold at from 4 to 6 annas per maund at the works, the second at from 3 to 4 annas. A considerable amount of small scales of mica remains in the kaolin (sp. 24·631). When I visited the quarries about twenty men were employed. The kaolin is used to produce a white glaze on a variety of pottery made in Delhi.

The kaolin locality Bachara, noted by Hackett² as in the Alwar hills, is really in Torawati (Jaipur) to the west. Buchara Latitude 27° 33', Longitude 76° 2'.

Rock crystal, quartz.

A pegmatite at Arangpur, 13 miles S. of Delhi, has been worked

¹ Baden Powell, *Punjab Products*, p. 42.

² *Rec., Geol. Surv. India*, XIII, p. 245.

in the past for rock-crystal.¹ The crystals are so small as to be quite useless (sp. 24'633).

Steatite, "Ghia bhāta."

The only steatite deposit in the area is at Dogetha (Dagota), 2½ miles N.E. of Raialo in Jaipur territory, situated in one of the highly ferruginous portions of the Raialo limestone. The width excavated is about 30 yards, but the deposit is considerably wider, as the country rock on either side is not laid bare. It runs diagonally, dipping at 80° W. by S., across the end of one the hills formed by the ferruginous rock, and is only excavated for some 50 or 60 yards along the length of the deposit, in an open cutting.

The steatite is very pure, milky-white or faintly tinged with green, with very thin films of pink ferruginous matter in some of the joints. The joints are irregular and allow of blocks up to a foot or so in dimension being extracted, but most of the material is in much smaller pieces than this, and no particular endeavour is made to get large ones. Here and there are small pockets of cellular quartz. The mass is quite structureless except for the jointing, and no clue could be obtained as to its origin; in no place was a junction with the surrounding rock seen.

The excavation cost is about a rupee per six or seven maunds and transport to Dosa railway station is 2 annas per maund, on pack bullocks.

Rupees 3,000 is said to be the annual rent paid for the quarry. From Dosa the steatite goes by rail, chiefly to Amritsar and some to Cawnpore. All connected with the industry professed ignorance as to the uses to which it is put, but from others I gather the opinions that it is used for finishing (sizing and weighting) cloth, as an ingredient in soap and as an adulterant in flour. One of the principal uses of steatite in India is as a polishing agent in rice-milling.

Marble.

Almost everywhere in the extensive area occupied by its outcrops, the Raialo limestone affords good marble, quarried chiefly in the vicinity of Raialo and Jhiri, in shallow surface workings. At both places the industry seems

¹ B. H. Powell's *Handbook of Punjab Economic Products*, p. 47.

to be in a much less prosperous state than formerly, and probably undergoes considerable vicissitudes, since the output depends almost entirely on the varying requirements of the Jaipur and Alwar Darbars.

The greater distance of Raialo and Jhiri from the railway, as compared with Makrana in Jodhpur, is a serious handicap, though the Makrana marble is said to be slightly inferior.

The stone is an excellent pure white saccharoidal marble, but most of the workings have not been carried deep enough to pass beyond the surface zone of open joints. (Sps. 23·62-3.)

Pink marble. A pink variety of the Raialo limestone is worked near Baldeogarh, but there is little demand for it.

Grey marble. A remarkably pretty pale grey variety is seen $1\frac{1}{2}$ miles N.W. of Raialo (sp. 23·60).

White marble is also quarried to a small extent at Dadikar, W. of Alwar City, a limestone band in the Alwar Series which has been altered by the

adjoining granite boss.

There are several bands of black siliceous limestone in the Ajabgarhs, but except at Loharwari and Mandla, in the hills east of Alwar City, they are not worked except for lime. The stone of the latter place is very soft and carbonaceous. (Sp. 23·112.)

One mile W. of Badgaon, near the Alwar-Jaipur frontier, is a small outcrop of a very handsome modification of the Kushalgarh limestone, well crystallised and remarkably free from joints. It is coloured black and white in narrow alternating bands (sp. 23·65).

Building stone.

The "Berla quartzite" (sps. 22·271-2, 22·283-4) described above, (p. 82) is quarried at all the large villages along the "M"-shaped double anticline south of Ghat, and a similar rock, but inferior in colour, at Mandla. It varies from white to dark-grey in pleasing shades, is soft and free from joints, hardens on exposure and is in inexhaustible quantity. Although the liability of some of it to iron-spotting on weathering restricts its use in the finest architectural structures, it is a most suitable material for public works, and its peculiar harsh

texture makes it admirable for grinding purposes. It takes rough carving well.

Many of the quarries are near railway stations and there is a considerable export. The workings are situated on the outcrops of the beds near the top of the ridge, and the blocks are slid down the scree-slopes.

The ordinary quartzites of the Alwar and Ajabgarh Series are

Ordinary quartzite. strong, but break irregularly and are too hard to chisel, so they are used only for rough buildings and village purposes.

There are many quarries of "patti" or "palti" (beams) and Micaceous quartzites. kátla" (paving stones), micaceous quartzites splitting readily into prismatic or flaggy pieces, of which the most noteworthy are at Rajgarh, Todiar, Mokaupura, Kirwari and Basi. At Mokaupura slabs up to 9 feet by 2 feet by 2 inches can be obtained for roofs and flooring, and for crudely carved brackets to support lintels and verandahs. These brackets are sold at 1 rupee to 4 annas each, according to size.

The Kirwari quarries are by far the most extensive and have a large export from Khirtal railway station; the Kirwari. largest slabs I saw were 6 feet by 3 feet by 2 inches, but most of the stone is got out in irregular diamonds about 4 feet by 1 foot by 6 inches, determined by jointing. Though hard and strong, their surfaces are rough and very liable to scaling, but the proximity of the quarries to the railway makes the stone cheap.

Slate.

The chief source of slate is the quarries near Kund railway station, worked by the Kangra Valley Slate Company. Kangra Valley Slate Company and two Indian companies.

They are really hardened shales rather than true slates, as they split along the bedding planes, which are almost vertical. Frequently there are thin films of iron oxide along the bedding planes, which render the slabs difficult to cut and cause them to wear unevenly, but the Kangra Valley Company have for several years been working an excellent band free from this defect and giving smooth, fissile, and even coloured and textured slabs. The slates are got in all sizes, chiefly for floorings. Roofing slates down to $\frac{1}{8}$ inch thickness are cut.

Mandan. On the same strike these slates are worked at Mandan, but are much inferior.

At Papri, near Pinangwan, is an exposure of true cleaved slates, but they are soft and imperfectly fissile and are not obtainable in large pieces (sp. 24·639).

Pinangwan.

In Crawford Campbell's paper¹ on the slates of Gurgaon, the Kund quarries are mentioned under the names of the adjoining villages Pali and Maneti.

Other slates, or rather shales and flaggy quartzites, are worked for village purposes at several places in the Ajabgarh Series, *e.g.*, Bilaspur, east of Alwar city.

Bitumen.

A curious surface deposit of bitumen is mentioned by Ball,² near Tijara, supposed to be due to the alteration of accumulated vegetable matter in contact with a saliferous soil.

Salt.

Salt is manufactured from brine-wells at Farrukhnagar, and was formerly extracted from similar brine near Nuh, but is not now worked.

¹ *Professional Papers on Indian Engineering*, IV, p. 257.

² *Geology of India*, Part III, p. 125; *Rec., Geol. Surv. India*, XXI, p. 5.

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| Skeat's dolomite test | 27. |
| Slate | 3, 79, 87, 127—128, see Ajabgarh Series. |
| Soil | 91, 100—102. |
| South Mahratta country breccias | 70. |
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| ——, thermal | 4—6, 50. |
| Stratification, Ajabgarh slates | 74. |

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| ———, Raialo limestone | 26. |
| ———, ——— quartzite | 24. |
| Staurolite | 73, 80, 83, 86, 95 |
| Steatite | 125. |
| <i>Sterculia urens</i> | 104. |
| Talus slopes | 31, 100. |
| <i>Tamarindus indica</i> | 104. |
| <i>Tamarix</i> | 101. |
| <i>Tectona grandis</i> | 104. |
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| Topography, Alwar Series | 3, 8, 31, 34—35, 38, 43, 49, 53. |
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| “Trap-shotten gneiss” | 72. |
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Junction—

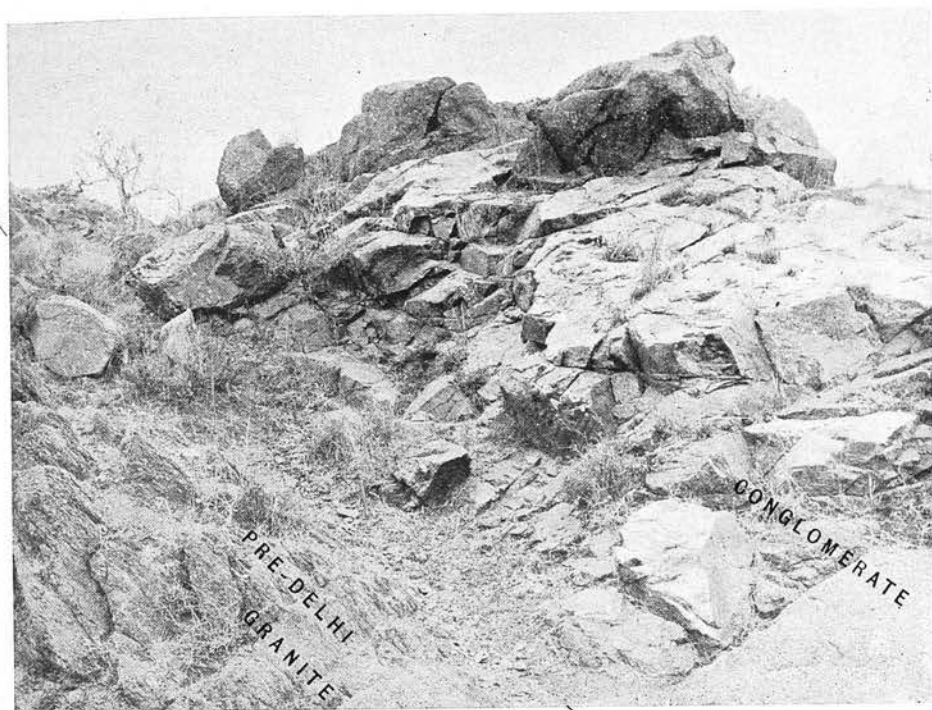


FIG. 1—BASAL ALWAR CONGLOMERATE: SABRAOLI, JAIPUR.



Photographs by A. M. Heron.

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FIG. 2—RELIEF WEATHERING OF CONTORTED SILICEOUS LAYERS IN RAIALO LIMESTONE E. OF GOND PURA, ALWAR.

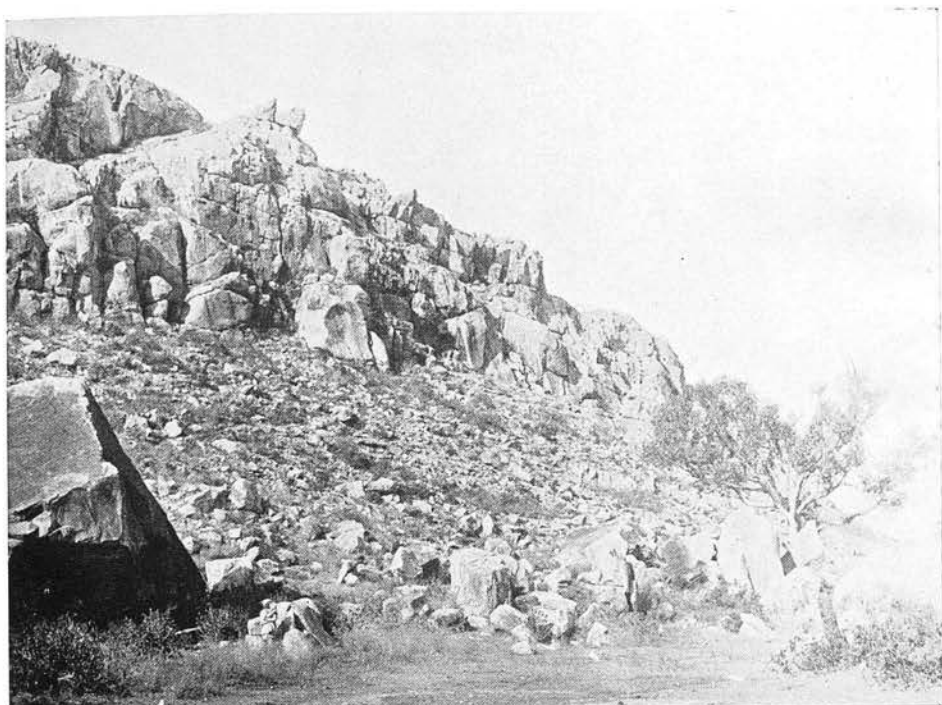
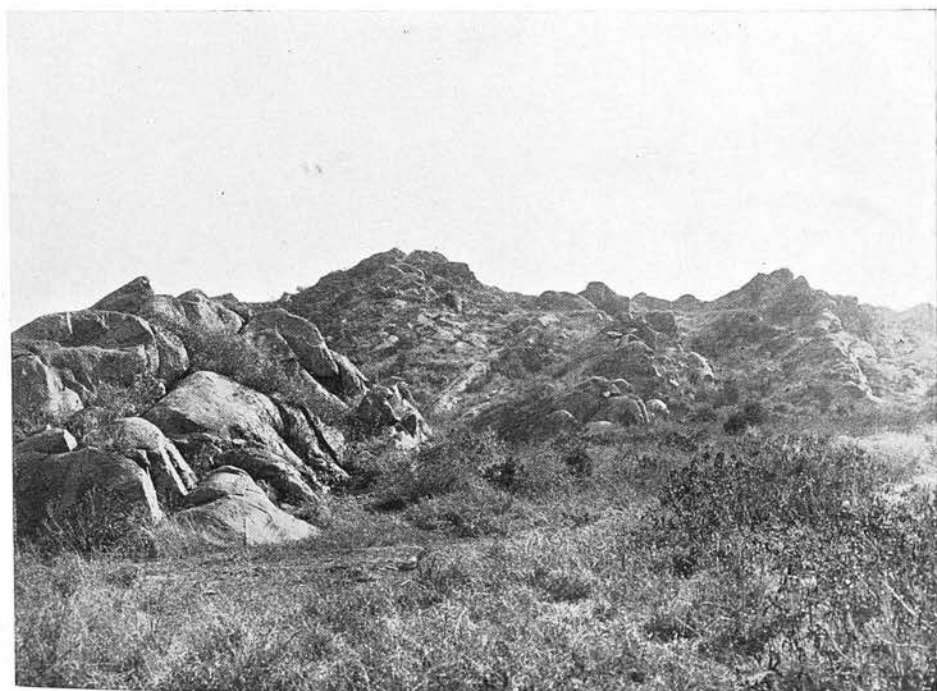


FIG. 1—THE "SERRATE" QUARTZITE AT BASE OF ALWAR SERIES, RAMPUR, ALWAR.



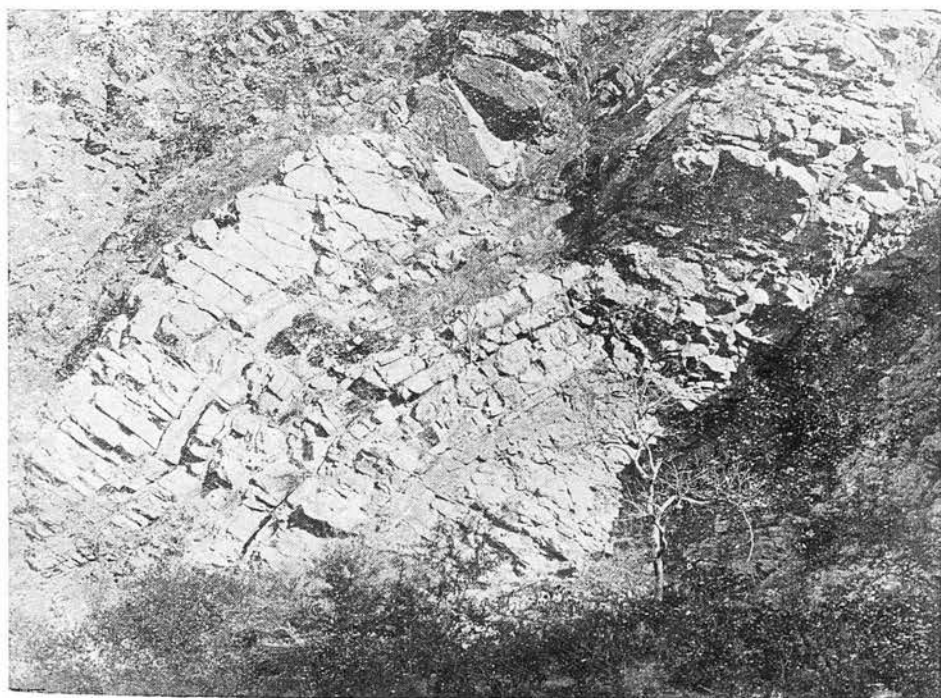
Photographs by A. M. Heron.

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FIG. 2—ALWAR GRITS, CONGLOMERATIC, WEATHERING LIKE GRANITE,
SOUTH OF GEWAR, ALWAR.



FIG. 1—ALWAR QUARTZITES showing typical bedding, jointing, and talus slope.
Bhiajar, Jaipur, looking north.



Photographs by A. M. Heron.

G. S. I. Calcutta.

FIG. 2—TWISTED ALWAR QUARTZITES, with typical bedding and jointing. Sukholo, Alwar.

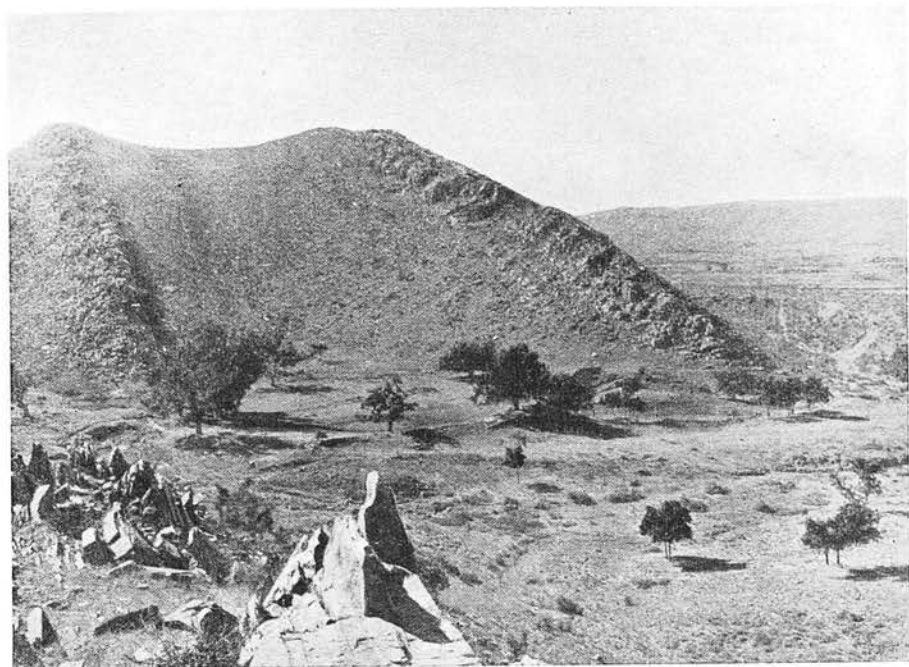
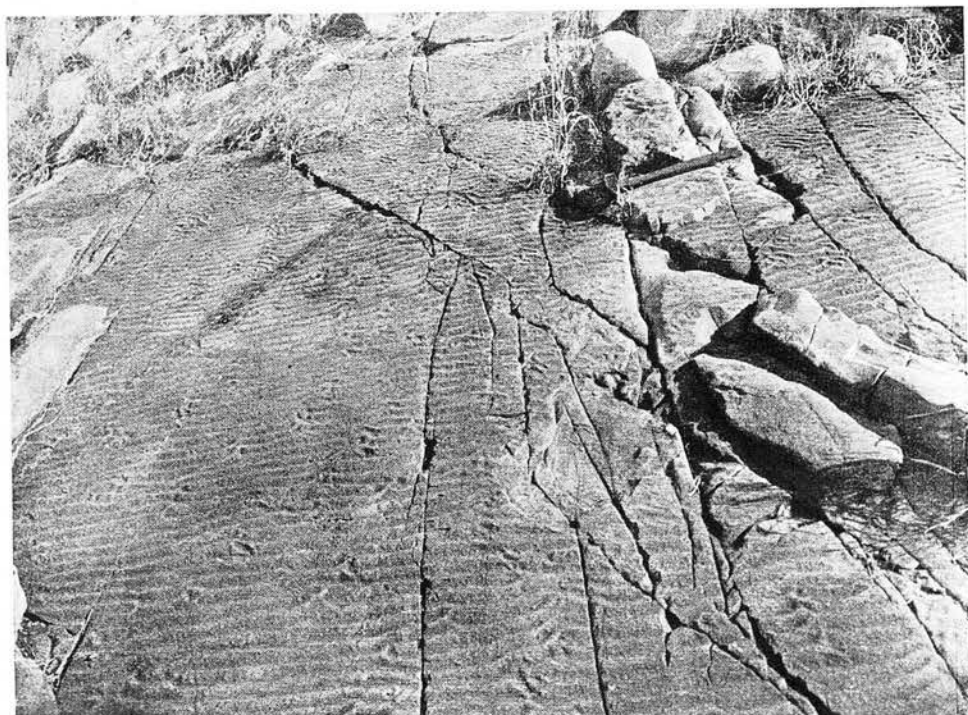


FIG. 1—ALWAR QUARTZITES DIPPING AT 70° . Jharoli, Alwar, looking S. W.



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FIG. 2—RIPPLE-MARKED ALWAR QUARTZITES. Below Kraska, Alwar.

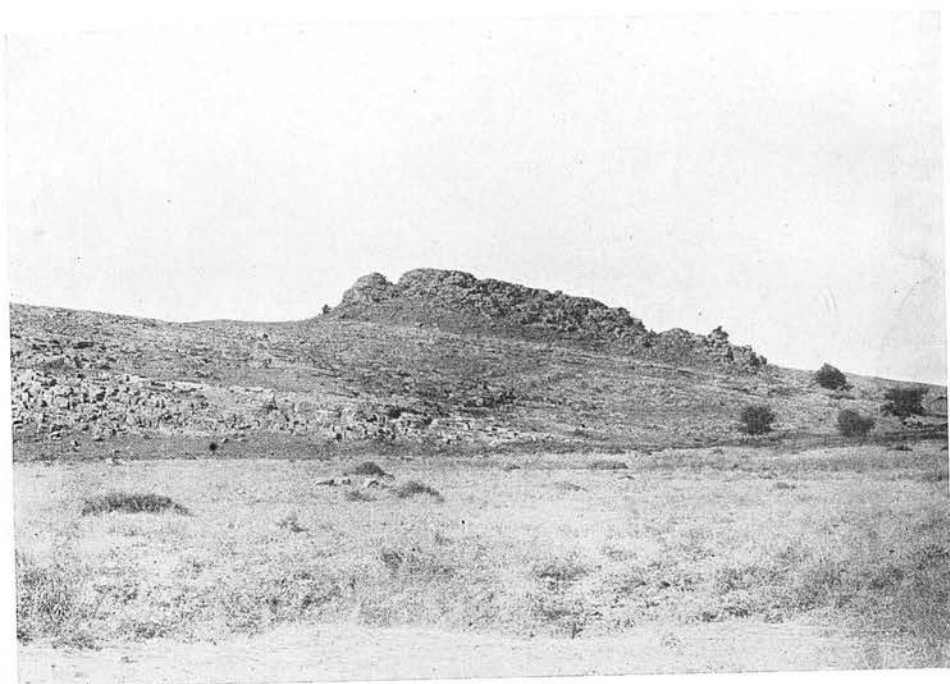
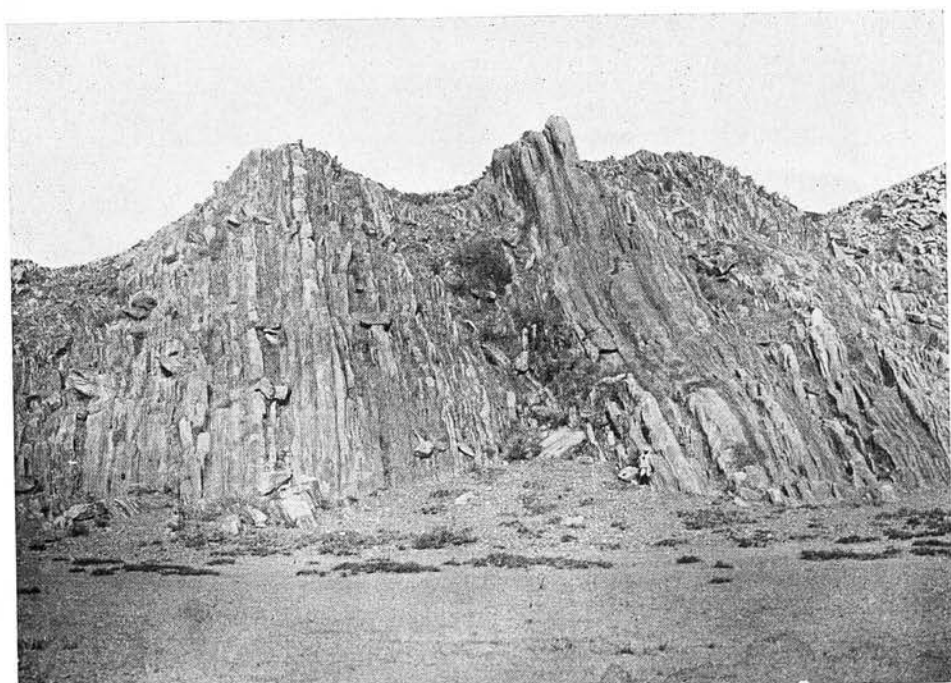


FIG. 1—ABNORMALLY LOW-DIPPING ALWAR QUARTZITES. SAROLI.



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FIG. 2—VERTICAL ALWAR GRITS. NARAINI .., ALWAR, LOOKING WEST.

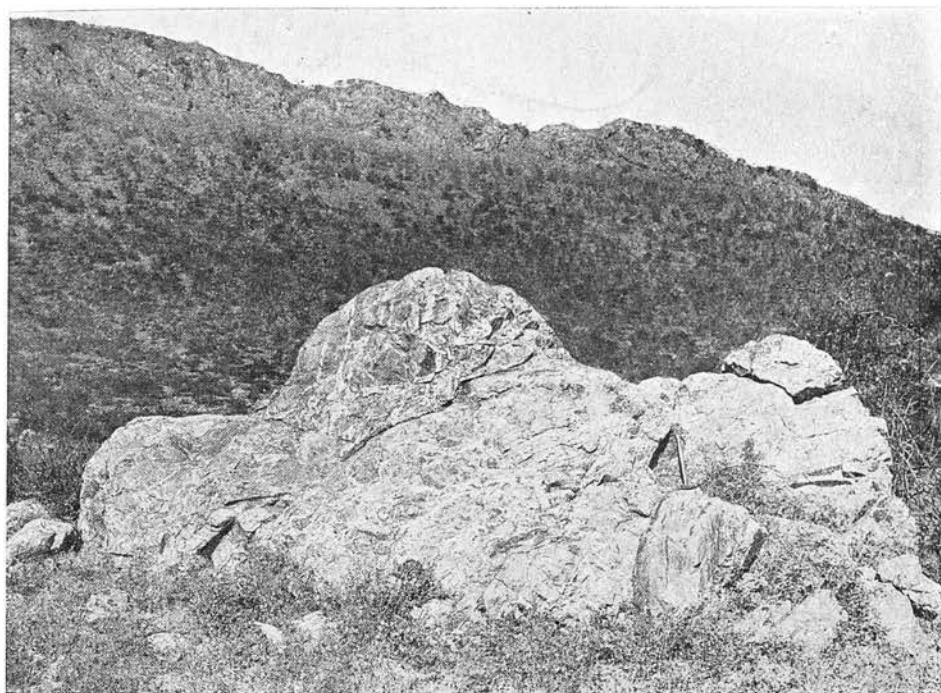
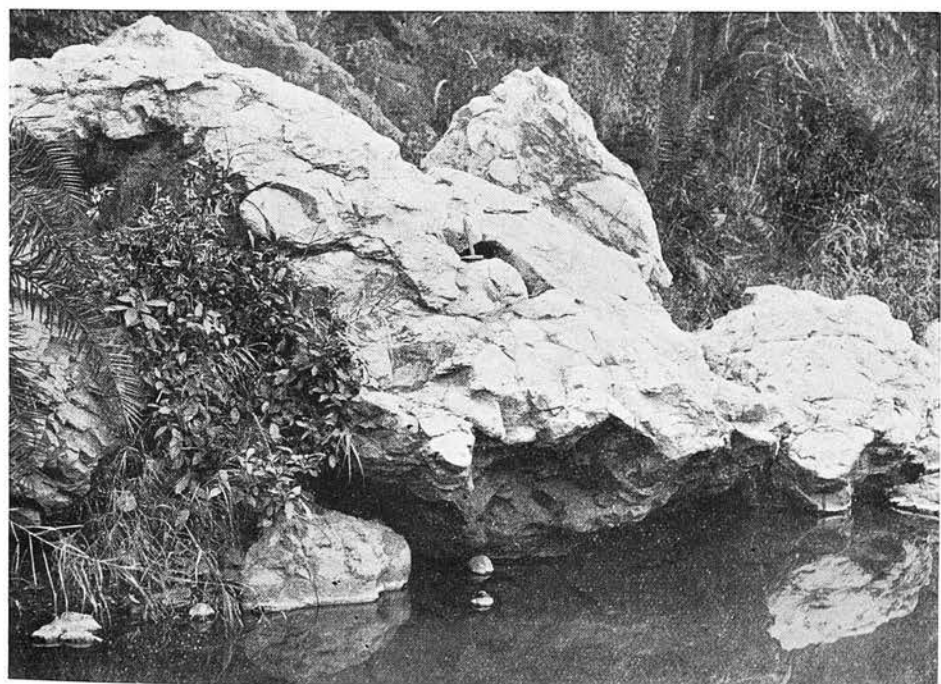


FIG. 1—BRECCIATED ALWAR QUARTZITE, HEAD OF DELAWAS VALLEY.



Photographs by A. M. Heron.

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FIG. 2—CONGLOMERATE IN ALWAR SERIES, ENTRANCE TO SILIBERI KHO.

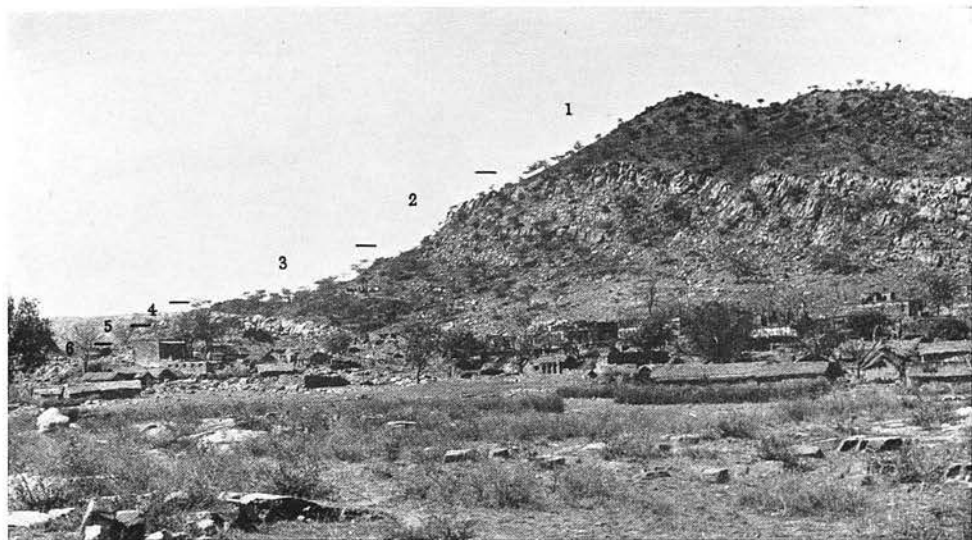
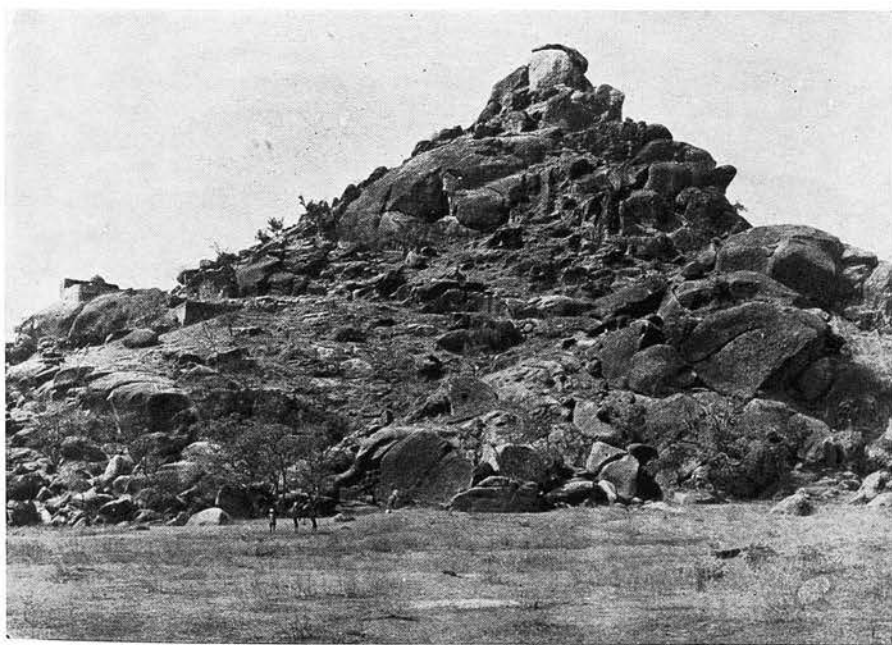


FIG. 1—INTERBEDDED ALWAR QUARTZITES and AMPHIBOLITE SILLS. SEMRA, looking west. 1, 3 & 5 Amphibolite and 2, 4 & 6 Quartzite.



Photographs by A. M. Heron.

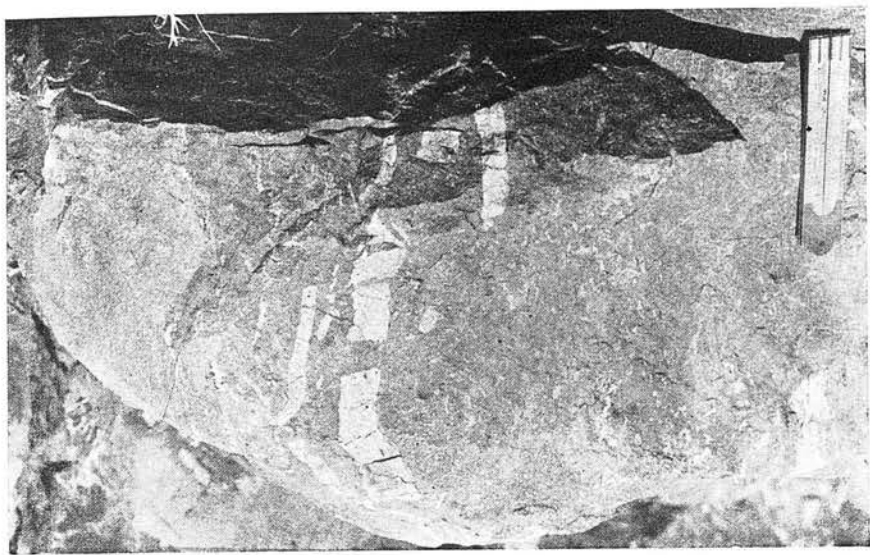
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FIG. 2—TYPICAL GRANITE HILL. SAMDA, ALWAR.



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FIG. 1—QUARTZITE (PALE) INJECTED WITH AMPHIBOLITE.



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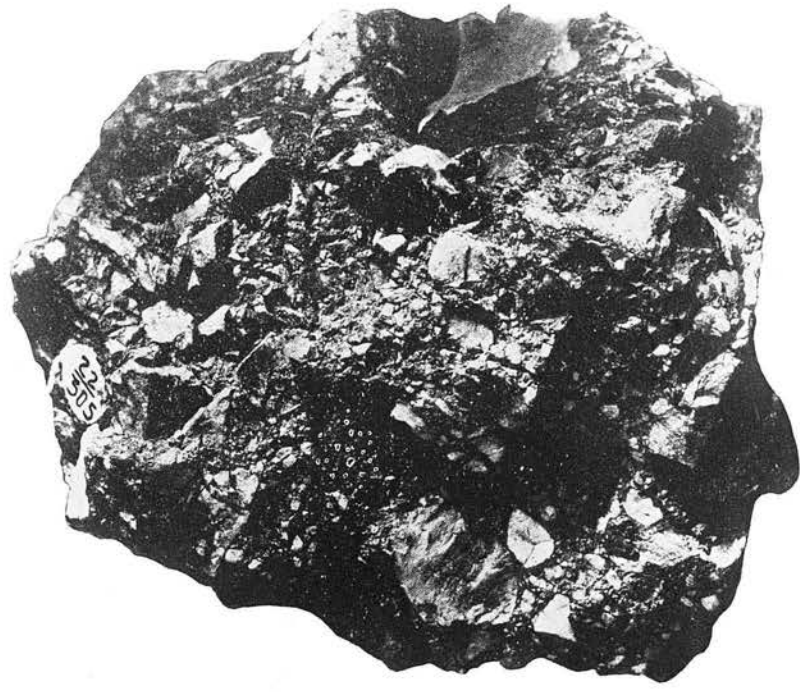
FIG. 2—SHATTERING OF QUARTZ IN HORNSTONE BRECCIA,
below dam of Deoti Lake.



Photographs by A. M. Heron.

FIG. 1.—HORNSTONE BRECCIA.

Fragments of fine black quartzite without distinct matrix. Veins of white quartz.



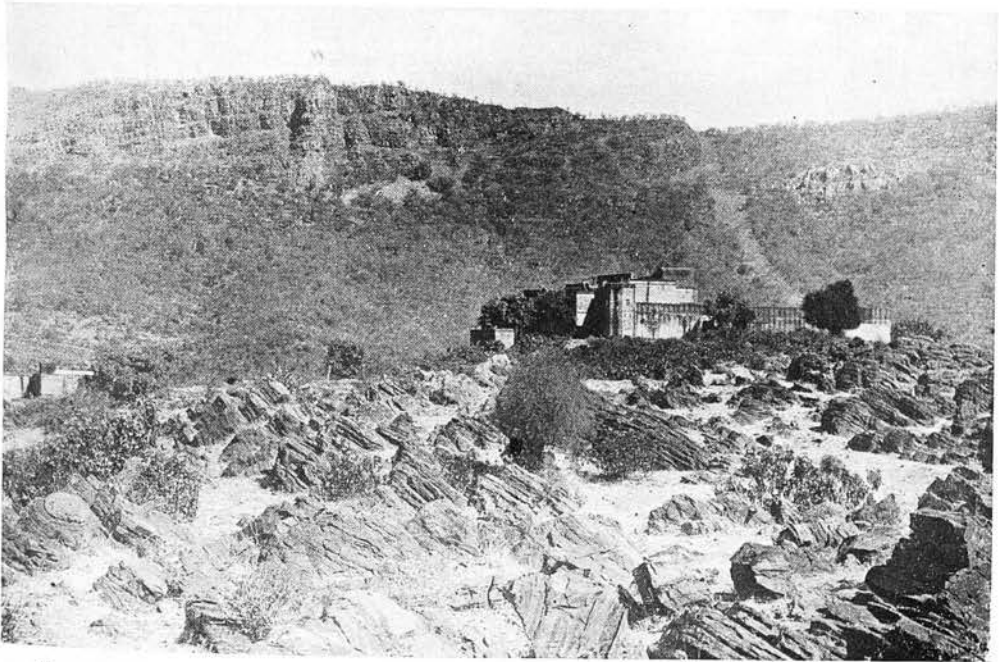
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FIG. 2.—HORNSTONE BRECCIA.

Dark quartzite fragments in a ferruginous matrix.



FIG. 1—VARIETY OF HORNSTONE BRECCIA.
Brecciated Ajabgarh Slates, below dam of Deoti lake.



Photographs by A. M. Heron.
FIG. 2—TYPICAL KUSHALGARH LIMESTONE, WITH SCARPS OF
Kushalgarh, looking N.

P. S. I. Calcutta.
T RE BEHIND.

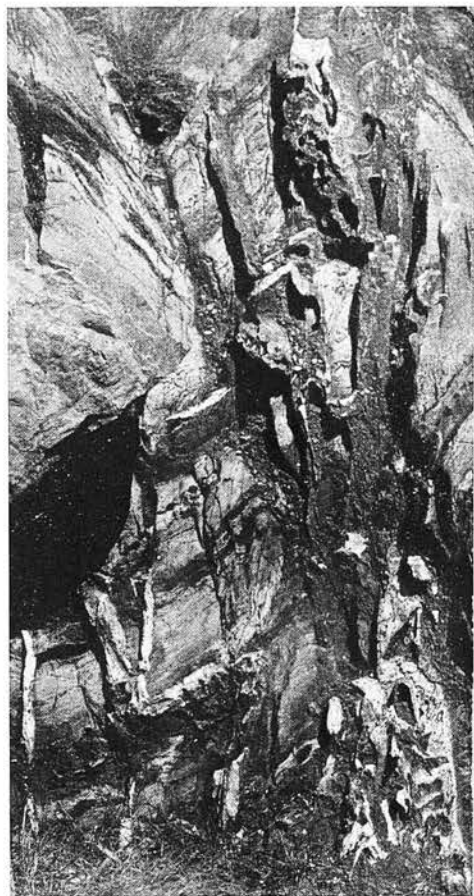
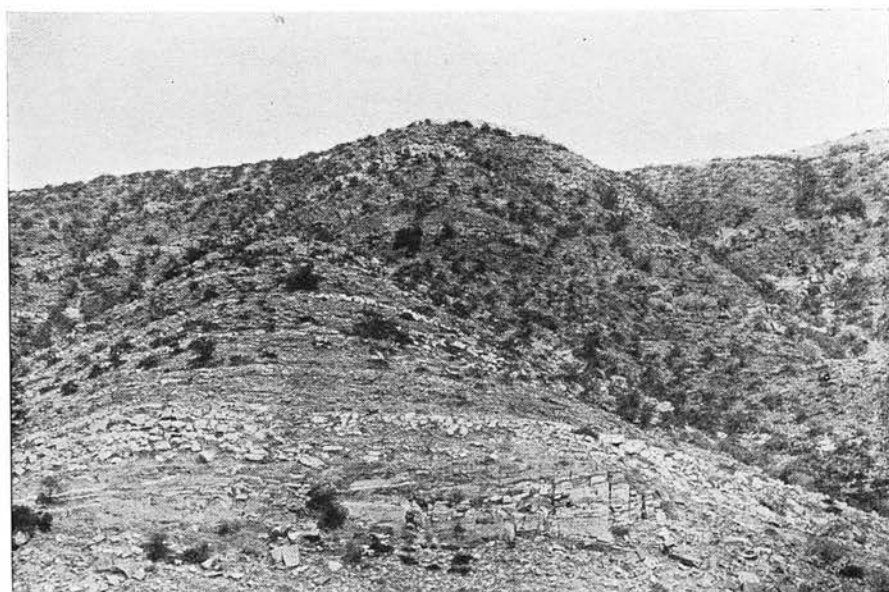


FIG. 1—QUARTZ-VEINED KUSHALGARH LIMESTONE. Simbubas, Alwar.



Photographs by A. M. Heron.

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FIG. 2—RAMIFYING QUARTZ VEINS MAINLY ALONG STRIKE IN AJABGARH
QUARTZITES AND SLATES. Tentpur, Alwar.

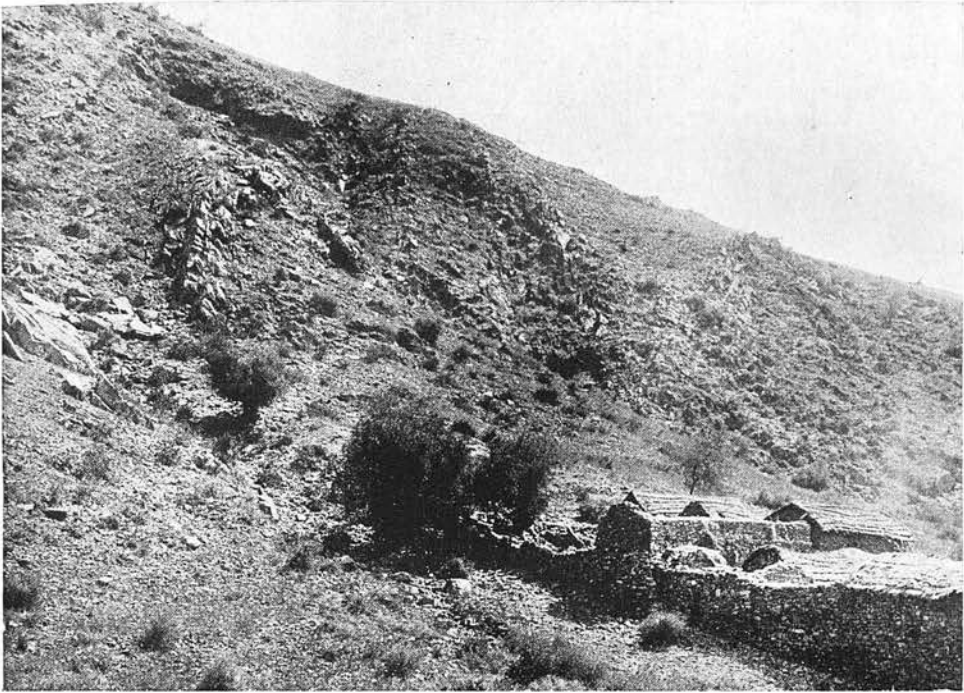


FIG. 1—THREE ANTICLINES IN AJABGARH QUARTZITES AND SLATES.
Narkho, Alwar, looking N.



Photographs by A. M. Heron.

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FIG. 2—TYPICAL OUTCROP OF INTERBEDDED AJABGARH QUARTZITES AND SLATES.
Showing ribbed effect, Kandoli, Alwar.

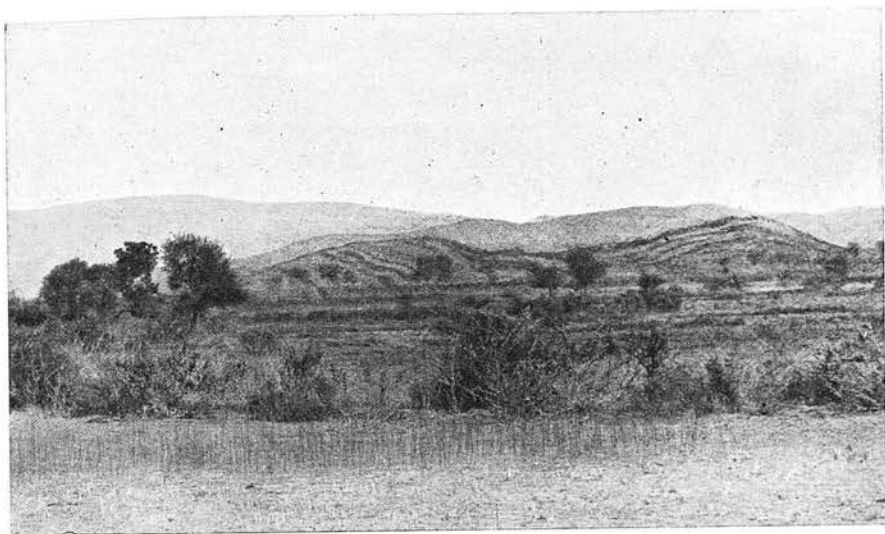
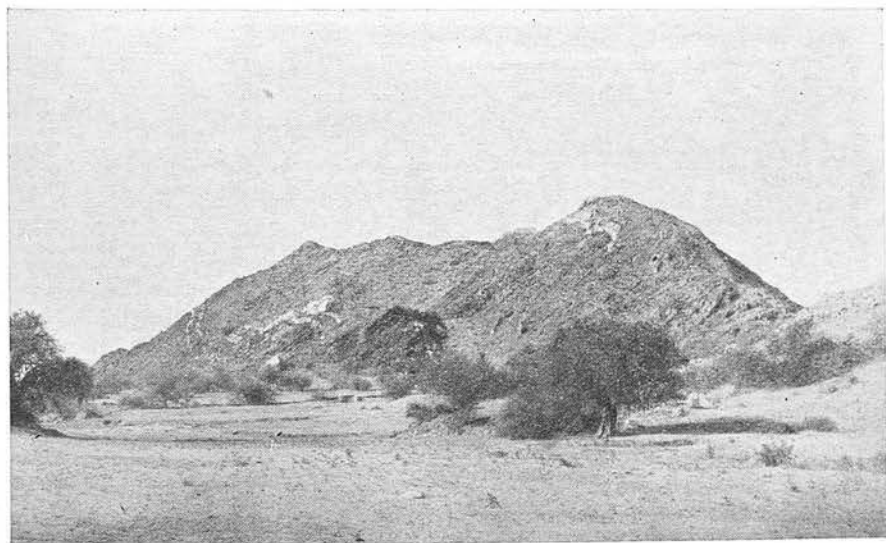


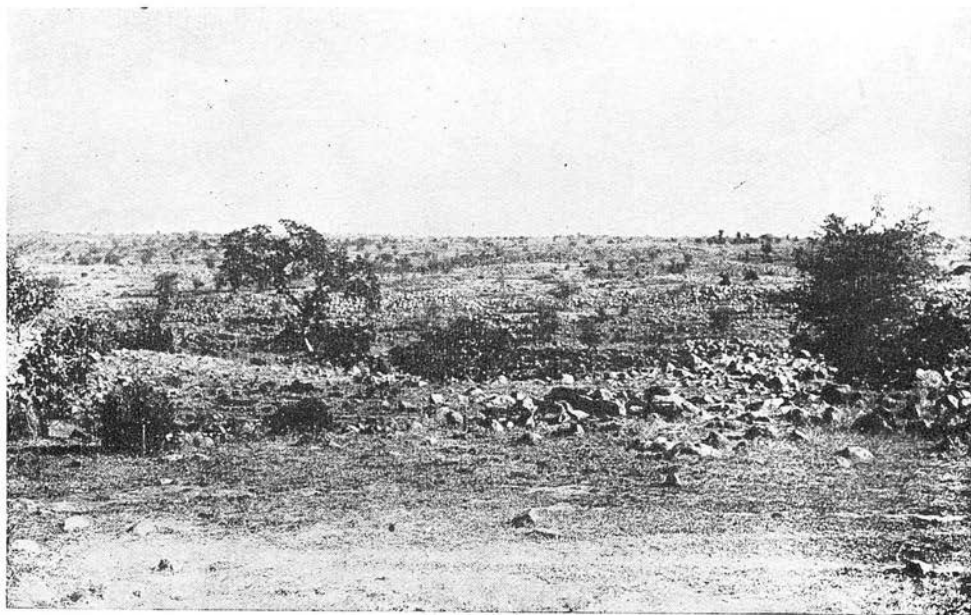
FIG. 1—CHARACTERISTIC RIBBED HILL OF AJABGARH QUARTZITE AND SLATES.
N. of Kilanpur, Alwar.



Photographs by A. M. Heron.

G. S. I. Calcutta.

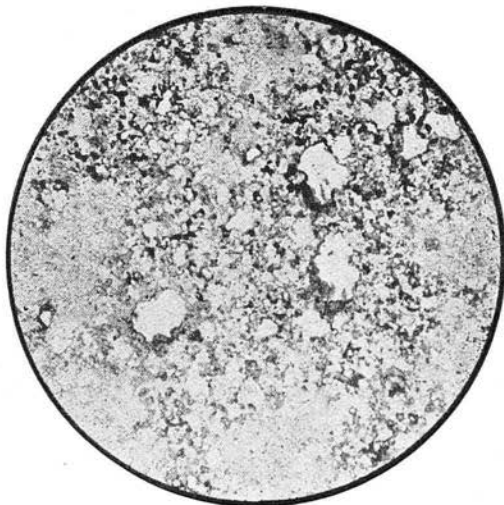
FIG. 2—HILL OF AJABGARH SLATES, traversed by quartz veins. Sabi river, N. E. of Barod.



1—PLATEAU OF ALWAR QUARTZITE SOUTH OF DELHI. Showing the level character of its upper limit.



2



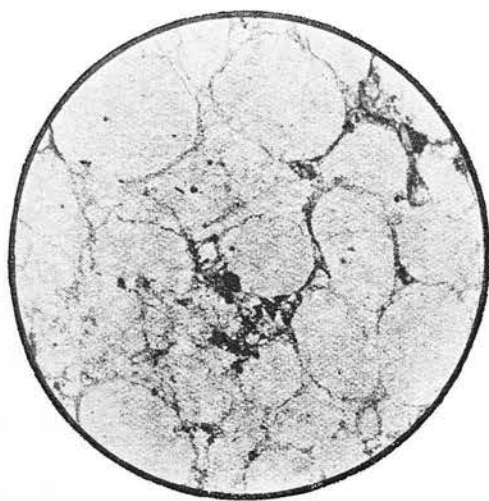
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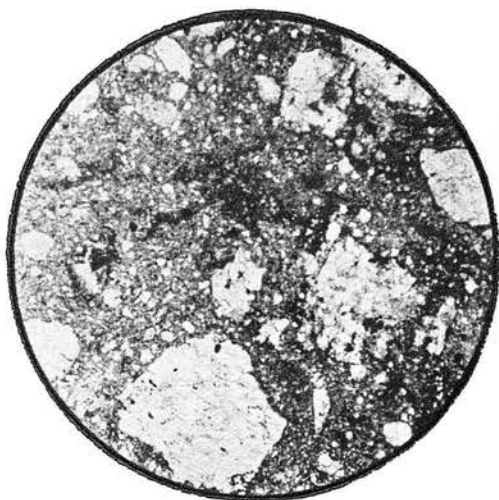
G. S. I. Calcutta.

2—Sillimanite needles in Alwar quartzite.

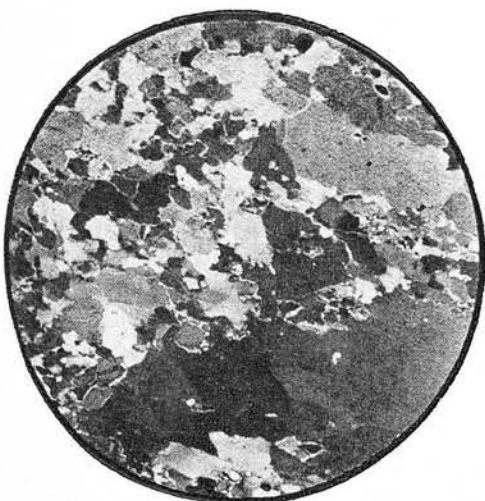
3—The Berla quartzite (Ajabgarh) showing cavities.



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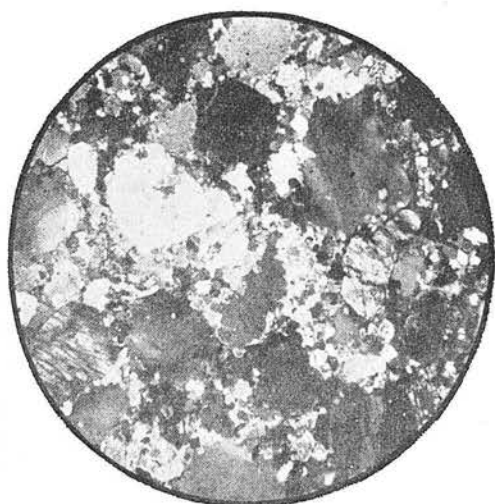


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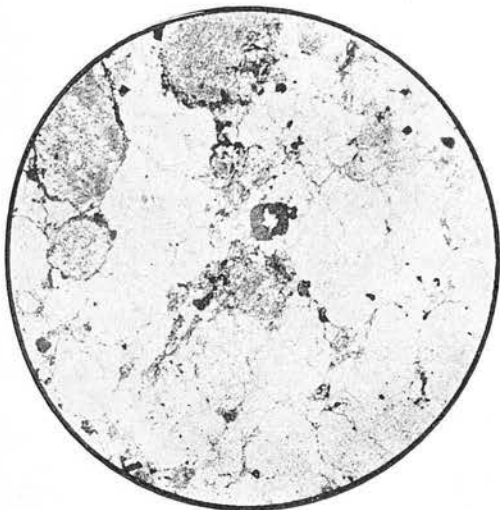
- 1—Quartz grit in Alwar series. Rounded undeformed grains.
- 2—Quartzite agglomerate (volcanic) in Alwar series. Angular quartzite fragments in ferruginous matrix.
- 3—Coarse Alwar quartzite XN. Quartz grains intercrystallised and showing undulating extinction.
- 4—Fine-grained Alwar quartzite XN. Quartz grains intercrystallised & showing undulating extinction.



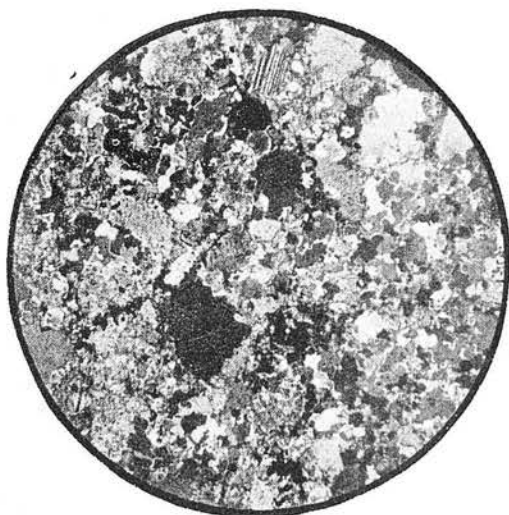
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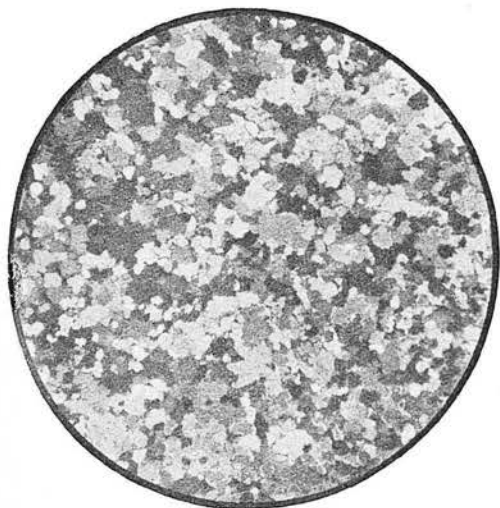


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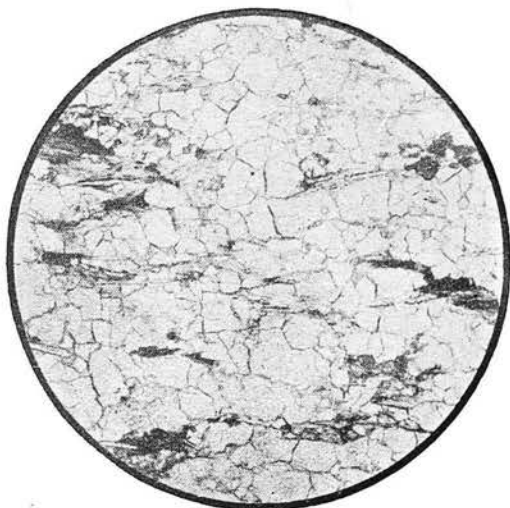
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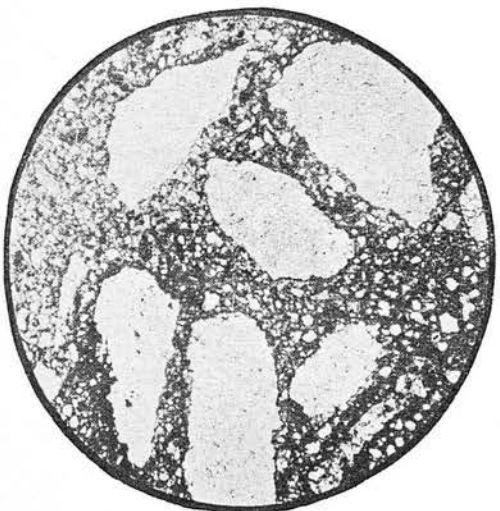
- 1—Arkose Alwar quartzite, XN, containing strained quartz, orthoclase and microcline and fine interstitial quartz.
- 2—Arkose Alwar quartzite, XN, component grains much compressed and interlocking.
- 3—Arkose Alwar quartzite, orthoclase grains at top, and tourmaline in centre
- 4—Arkose Alwar quartzite, XN, containing quartz, kaolinised orthoclase and plagioclase.



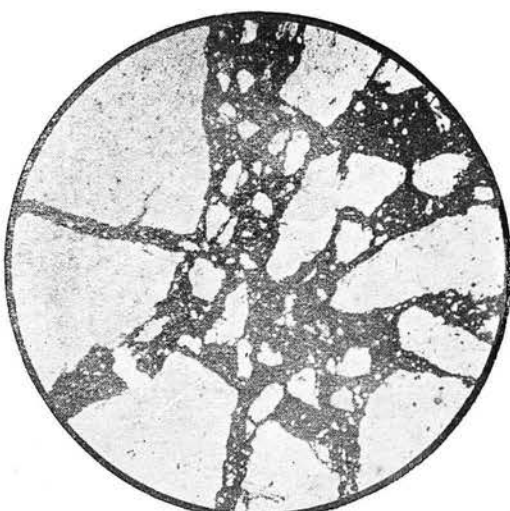
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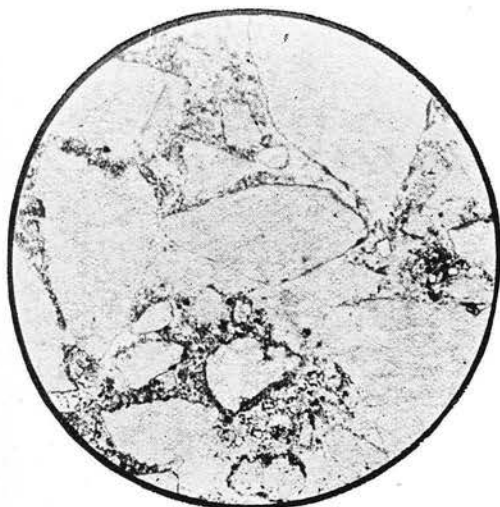
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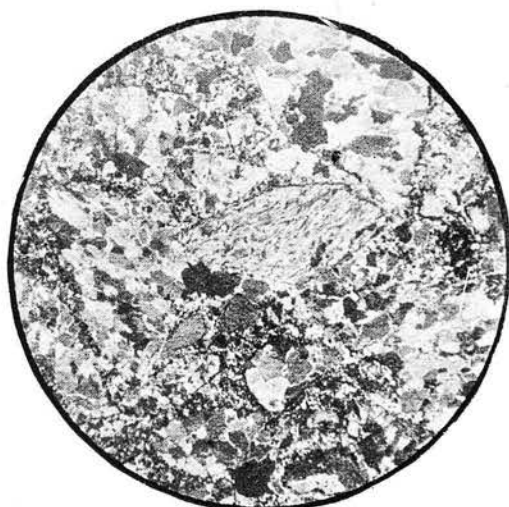
- 1—Fine-grained Alwar quartzite, XN.
- 2—Schistose Alwar quartzite showing muscovite and tourmaline in lines.
- 3—Hornstone breccia, quartzite fragments in limonitic matrix.
- 4—Hornstone breccia, fragments of fine quartzite brecciated in situ in limonitic matrix.

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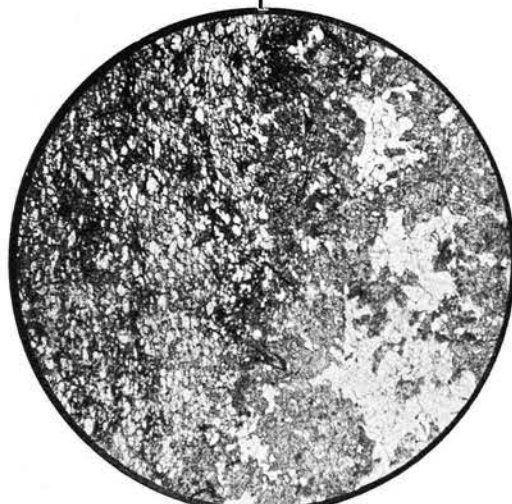
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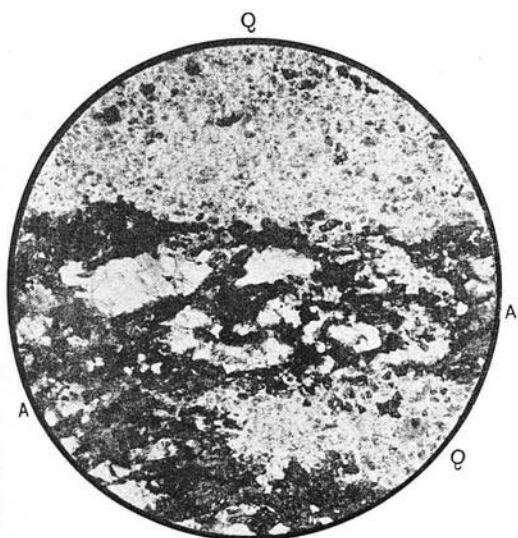
G. S. I. Calcutta.

1—Hornstone breccia of quartzite fragments.

2—Hornstone breccia of quartzite fragments, XN.

3—Hornstone breccia, fine-grained quartzite fragments in limonitic matrix.

4—Junction of fine ferruginous limestone (on left) with amphibolite containing coarse calcite (on right.)



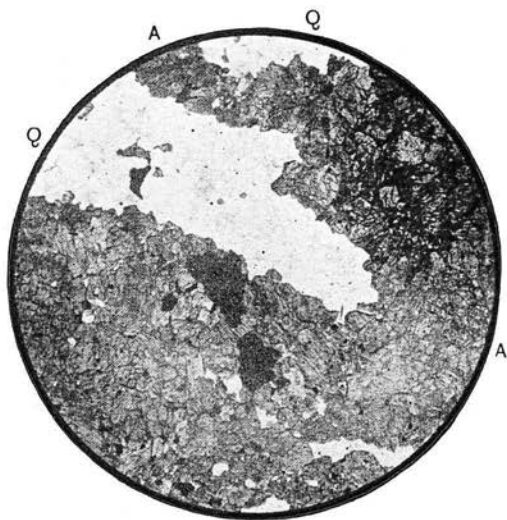
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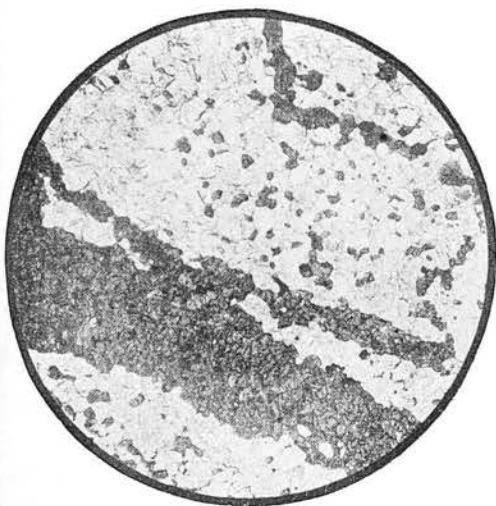


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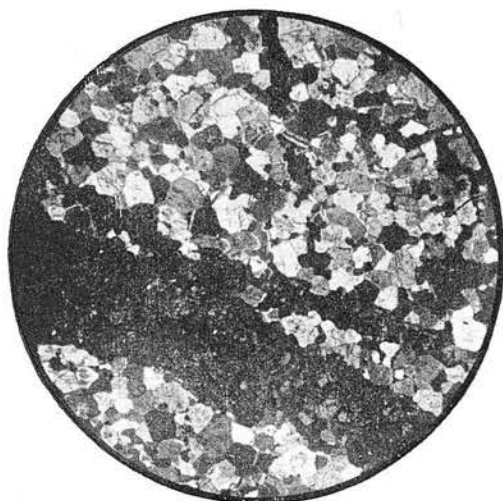
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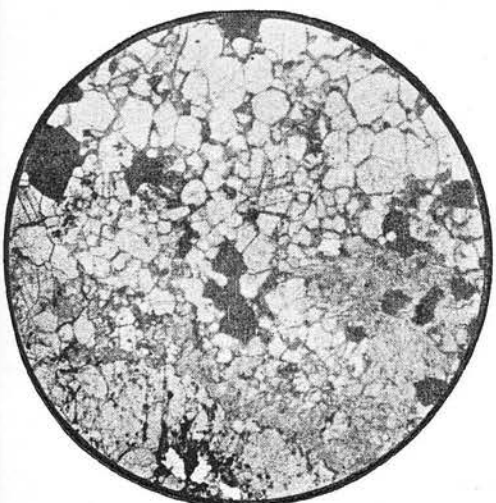
- 1—Amphibolite (A), penetrating quartzite (Q).
- 2—Amphibolite of medium grain.
- 3—Coarse grained amphibolite.
- 4—Amphibolite (A), nearly all hornblende, injecting quartzite (Q).



1



2



3



4

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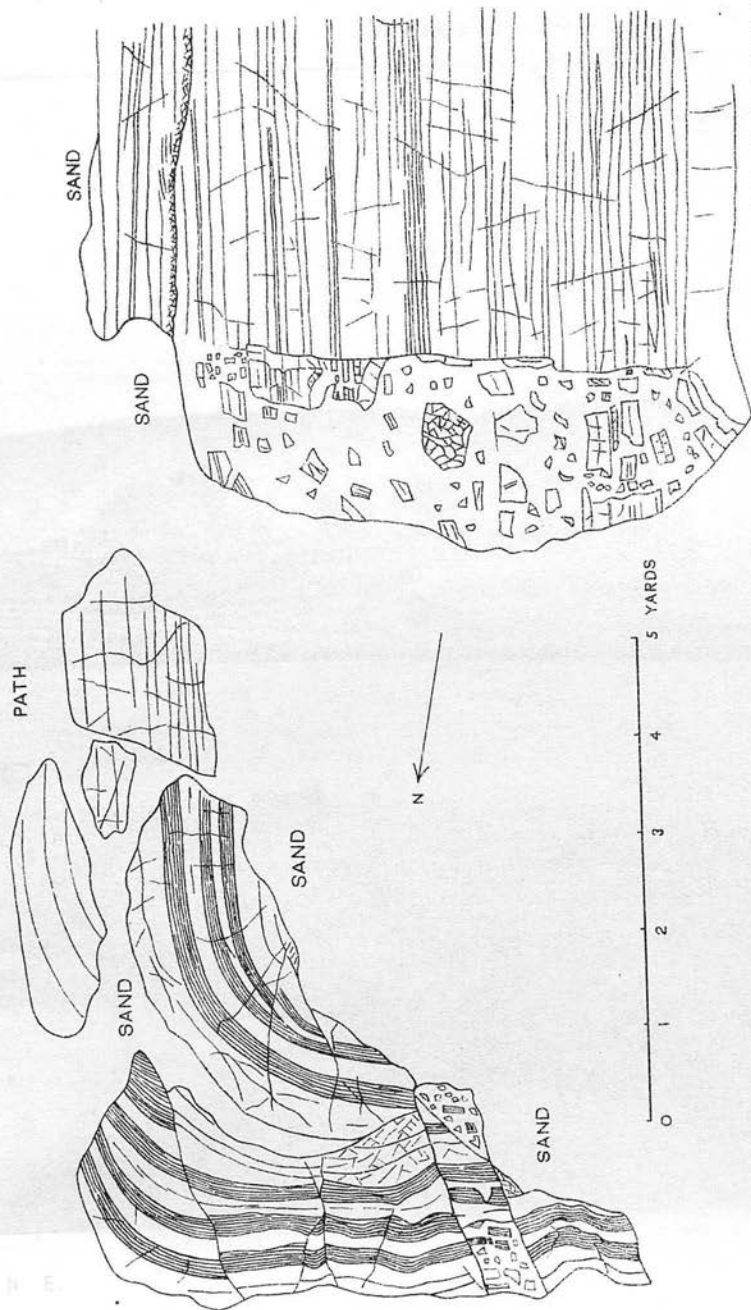
G. S. I. Calcutta.

1—Veinlets and scattered grains of amphibolite, injecting quartzite.

2—The same, with crossed nicols.

3—Raialo limestone with tremolite and grains of iron-ore.

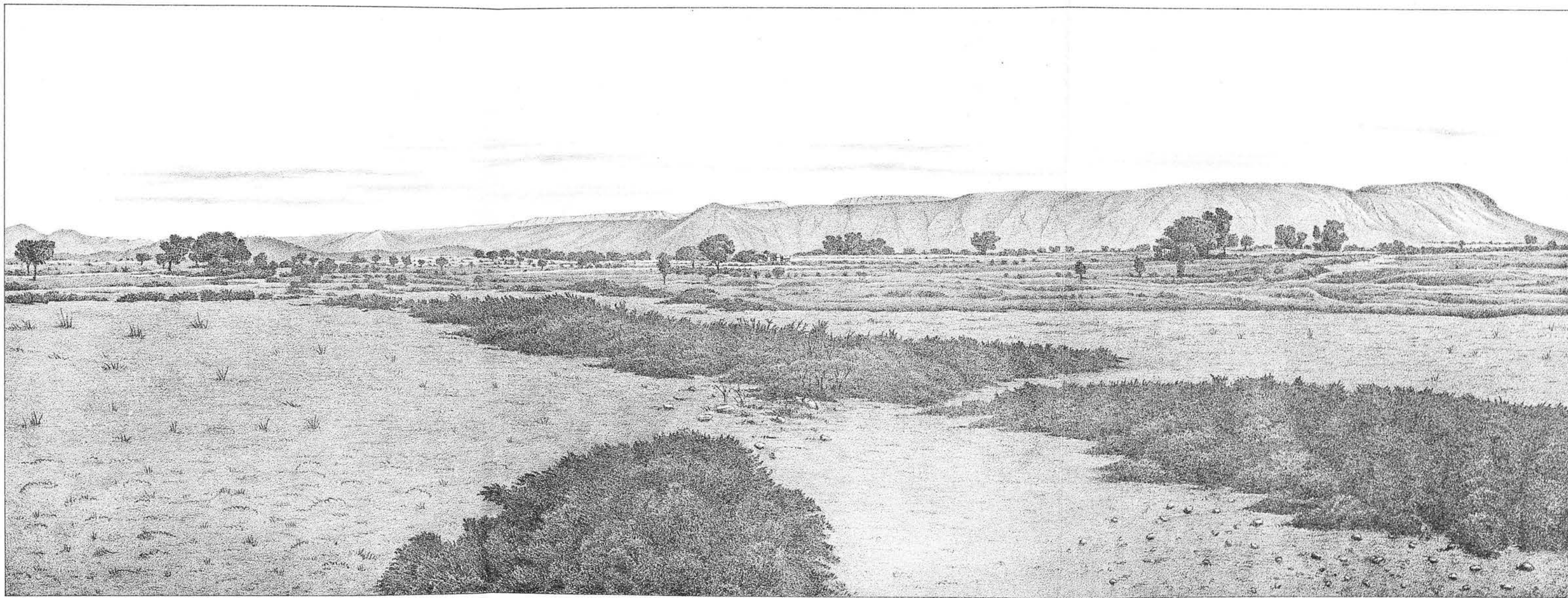
4—Brown cherty modification of Raialo limestone, at its top. Acicular limonite in quartz.



Litho G. S. I. Calcutta.

By A. M. Hearn.

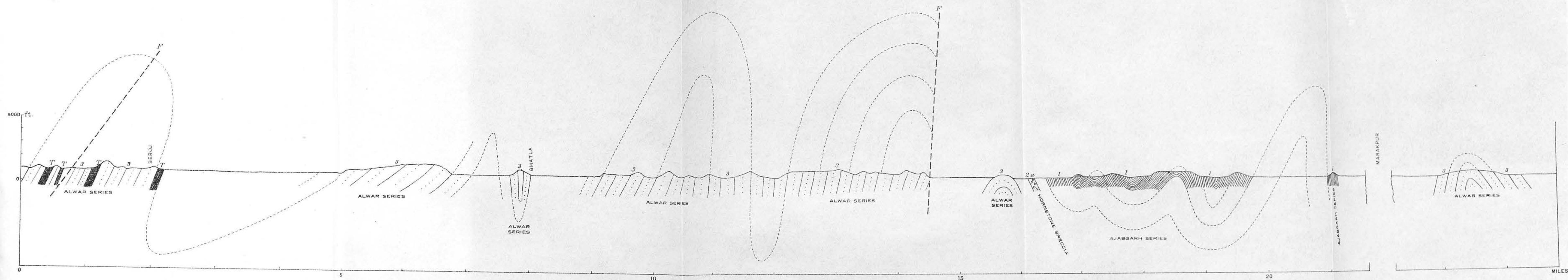
PLANE-TABLE PLAN OF BRECCIATED SLATES SOUTH OF EMBANKMENT OF THE DEOTI LAKE.



From a Photograph by A. M. Heron.

HILLS OF ALWAR QUARTZITES EAST OF NIMLA, showing their level summits. View looking E. & N. E.

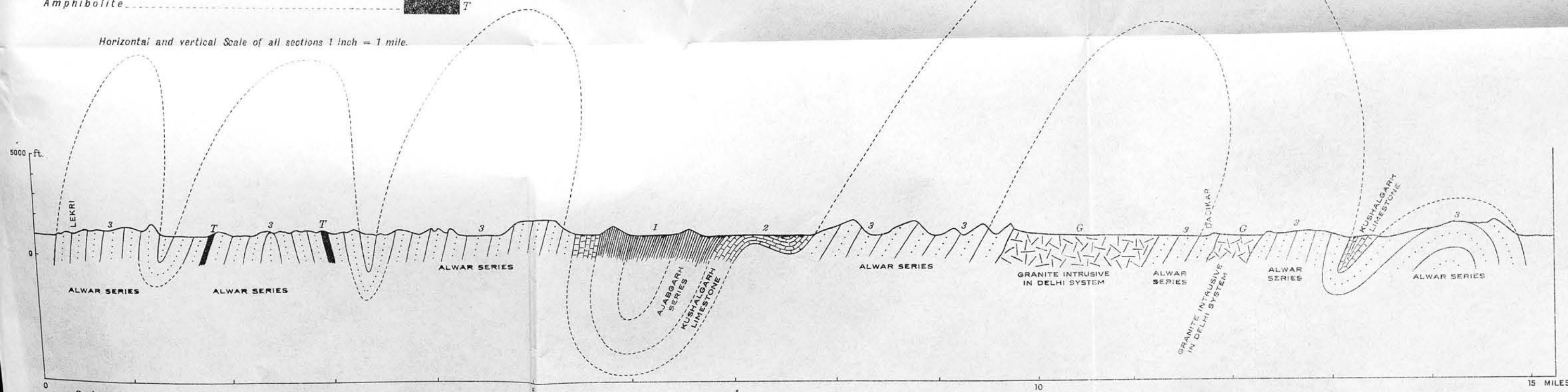
Litho. G. S. I. Calcutta.



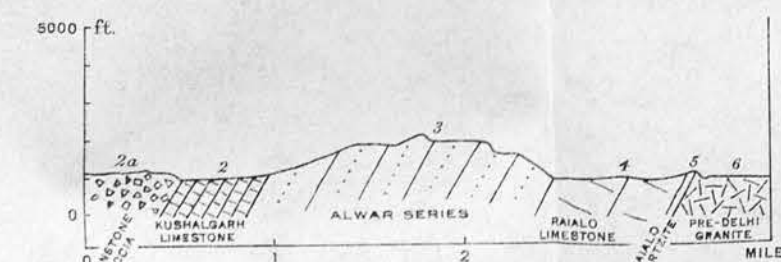
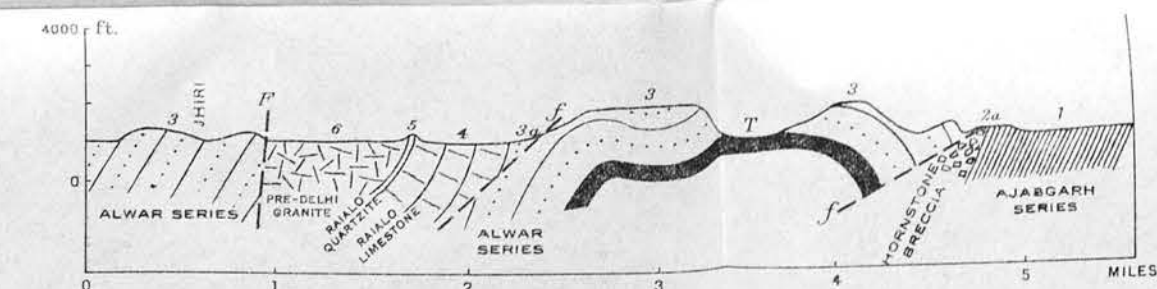
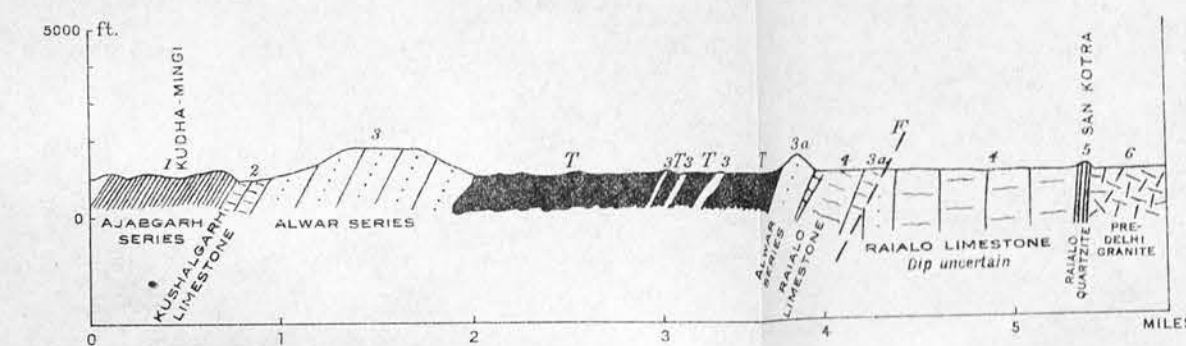
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Horizontal and vertical Scale of all sections 1 inch = 1 mile.



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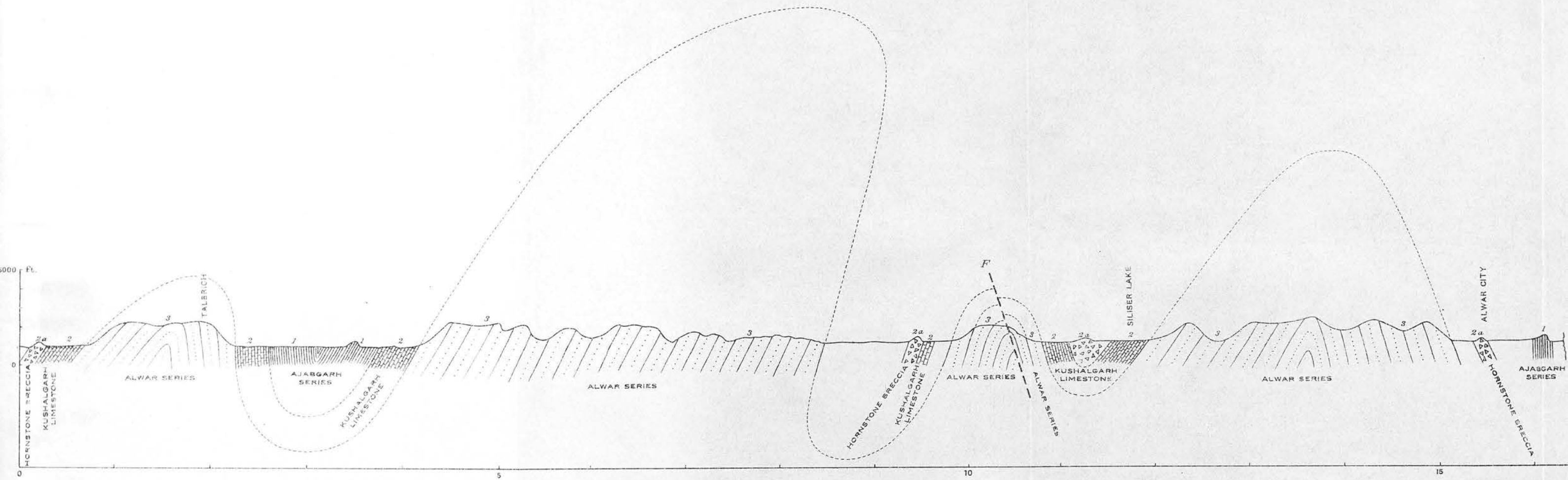
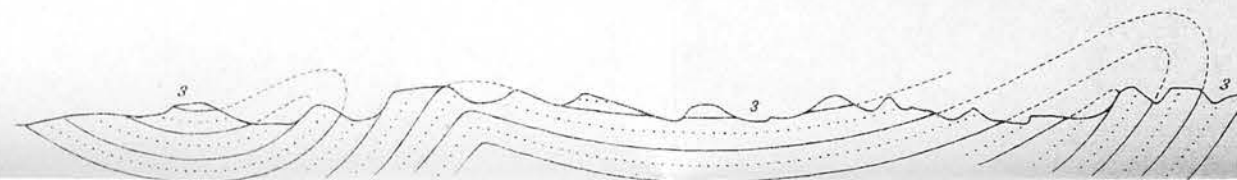
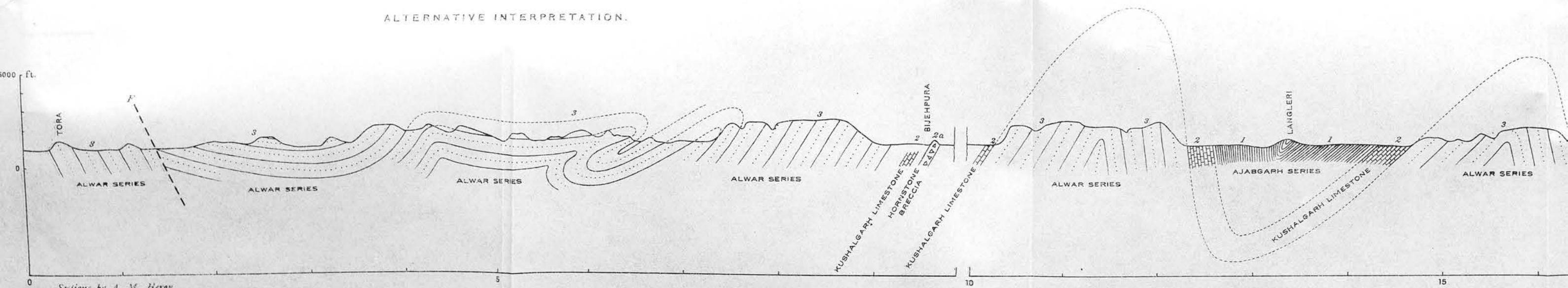


FIG. 1. SECTION THROUGH TALBRICH AND ALWAR E. 11° N. [Line F. F. of map.]



ALTERNATIVE INTERPRETATION.



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FIG. 2. SECTION FROM TORA TO LANGLERI (E. 16° S.) AND FROM LANGLERI TO DHAMALA (E. 4° N.) [Line F. F. of map.]

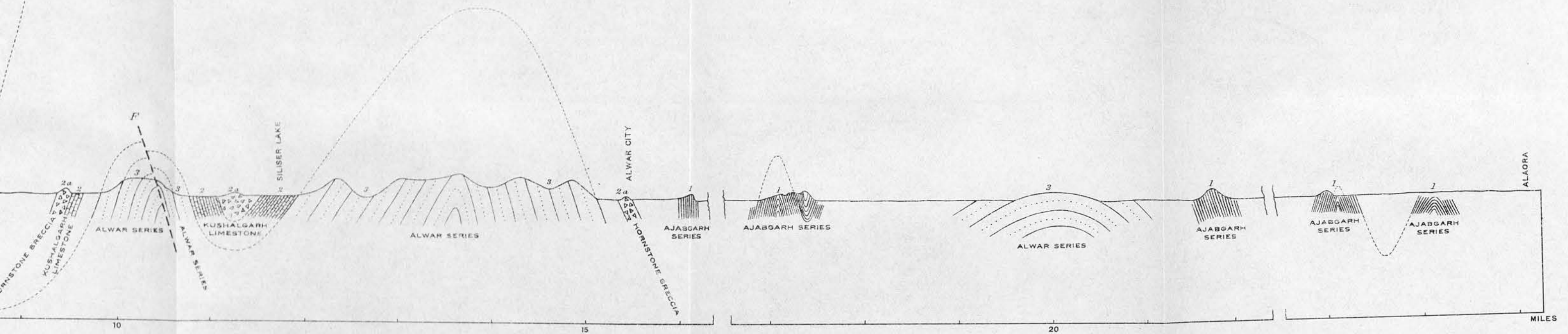
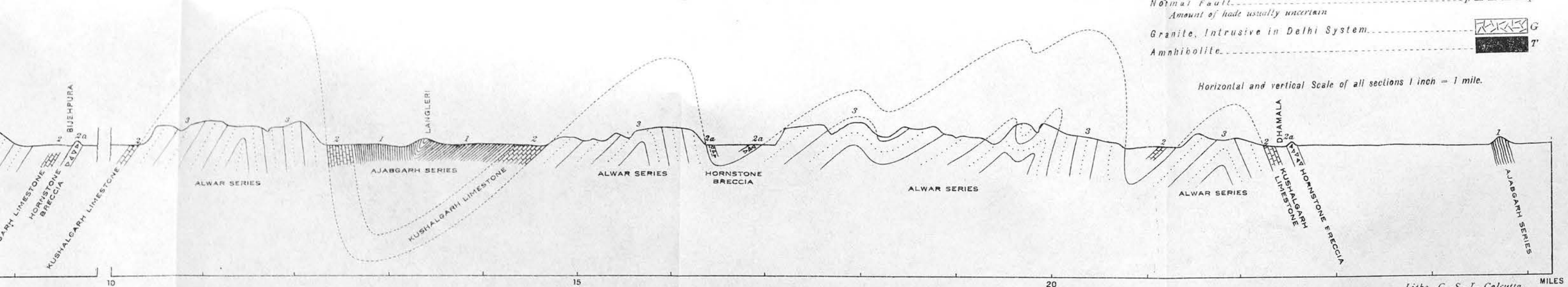


FIG. 1. SECTION THROUGH TALBRICH AND ALAORA E. 11° N. [Line F. F. of map.]

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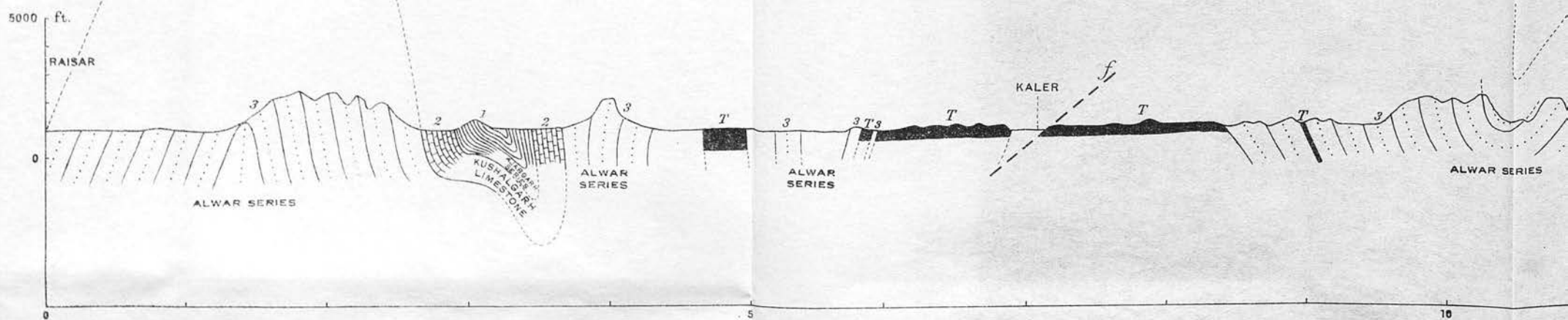
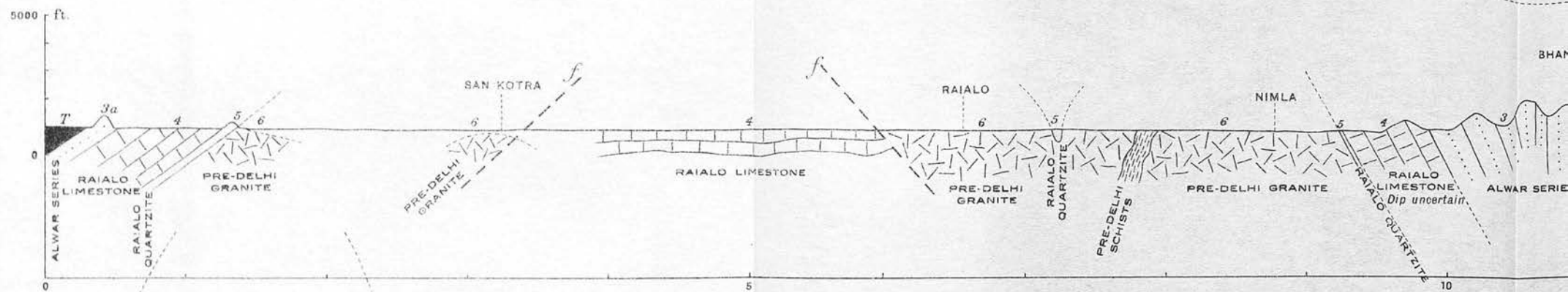
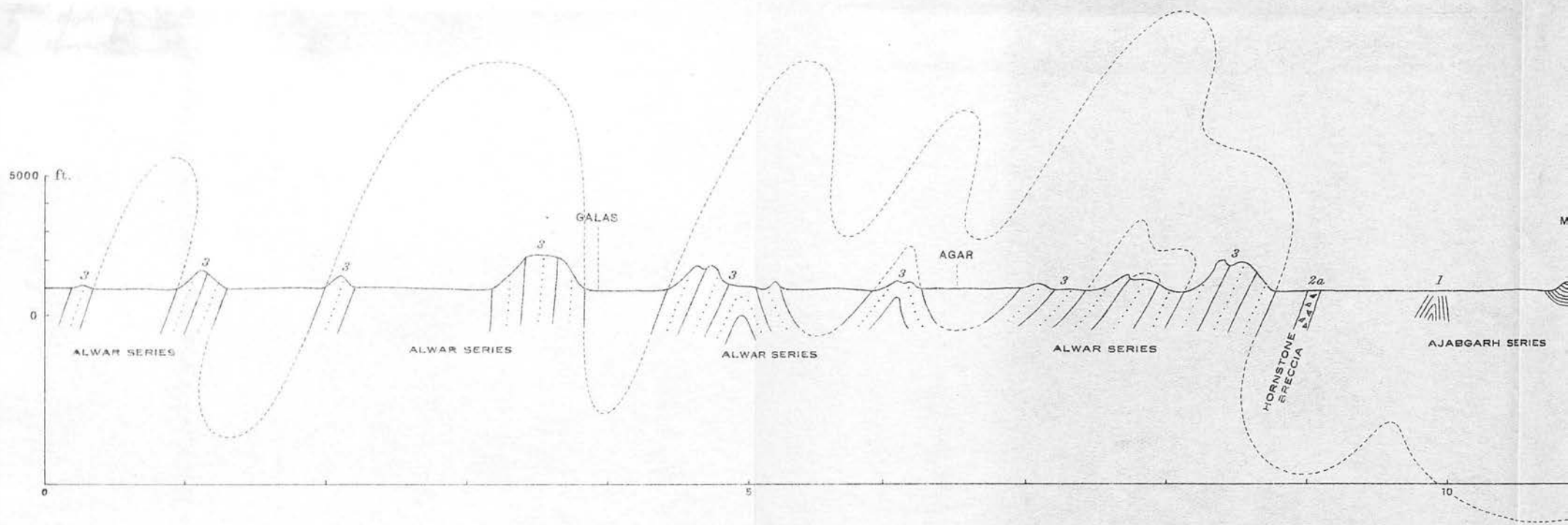
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| Ajabgarh Series | 1 |
| Kushalgarh Limestone | 2 |
| Hornstone Breccia | 2a |
| Alwar Series | 3 |
| "Serrale" Quartzite, base Alwar Series | 3a |
| Raialo Limestone | 4 |
| Raialo Quartzite | 5 |
| Pre-Delhi Granites, Limestone &c. | 6 |
| Reversed Fault | f—f |
| Normal Fault | f'—f' |
| Amount of hade usually uncertain | |
| Granite, Intrusive in Delhi System | G |
| Amphibolite | T |

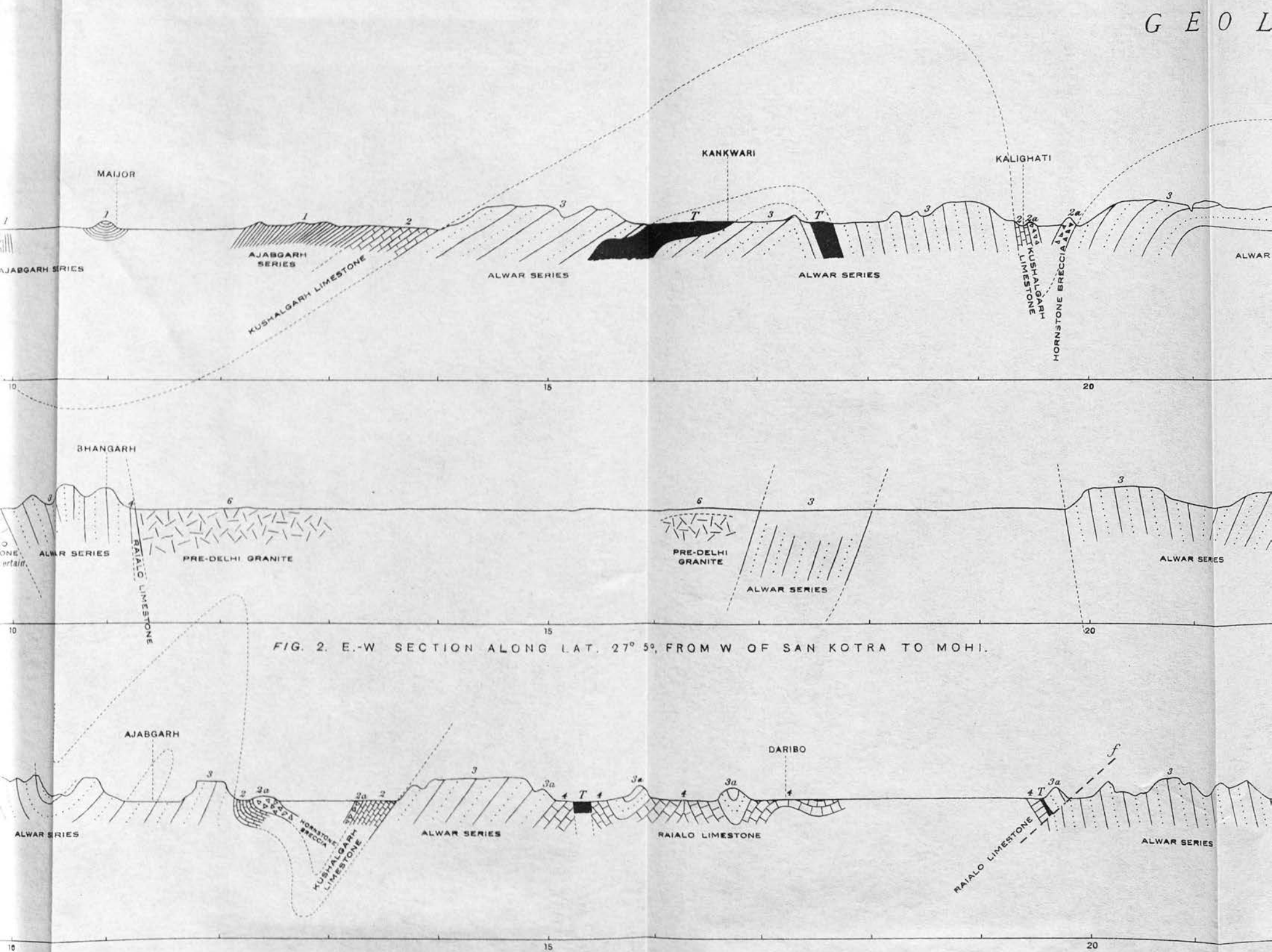
Horizontal and vertical Scale of all sections 1 inch = 1 mile.



2. SECTION FROM TORA TO LANGLERI (E. 16° S.) AND FROM LANGLERI TO DHAMALA (E. 4° N.) [Line G. G. of map.]

Litho. G. S. I. Calcutta.





GEOLOGICAL SURVEY OF INDIA.

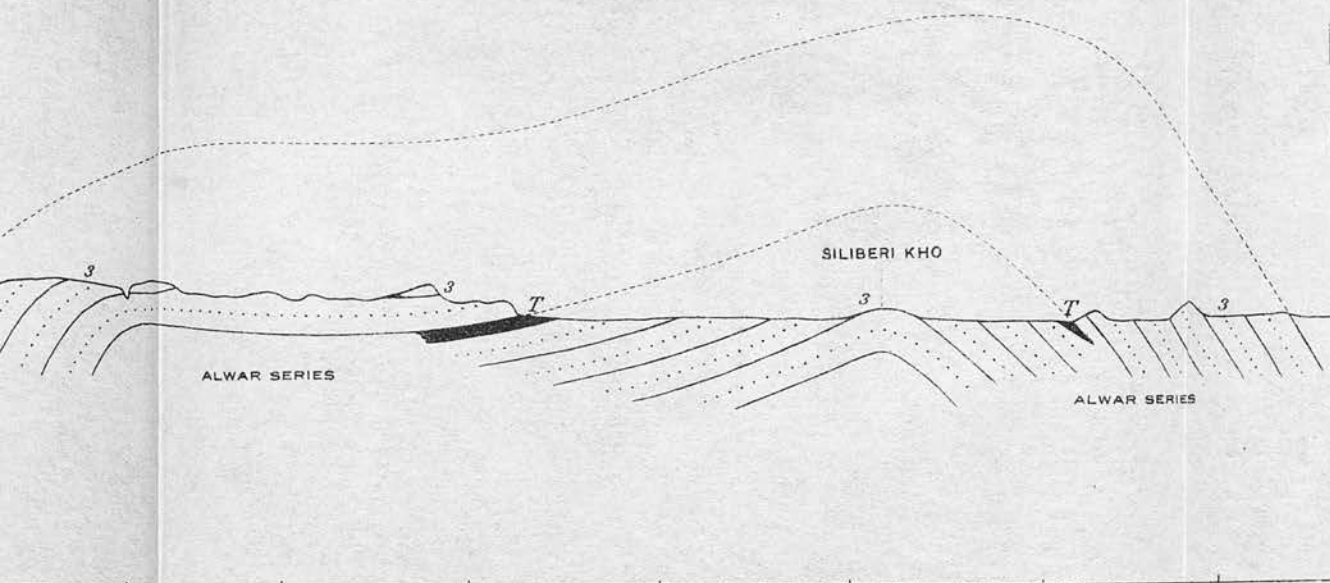


FIG. 1. E.-W. SECTION FROM GALAS TO PUNKAR AND

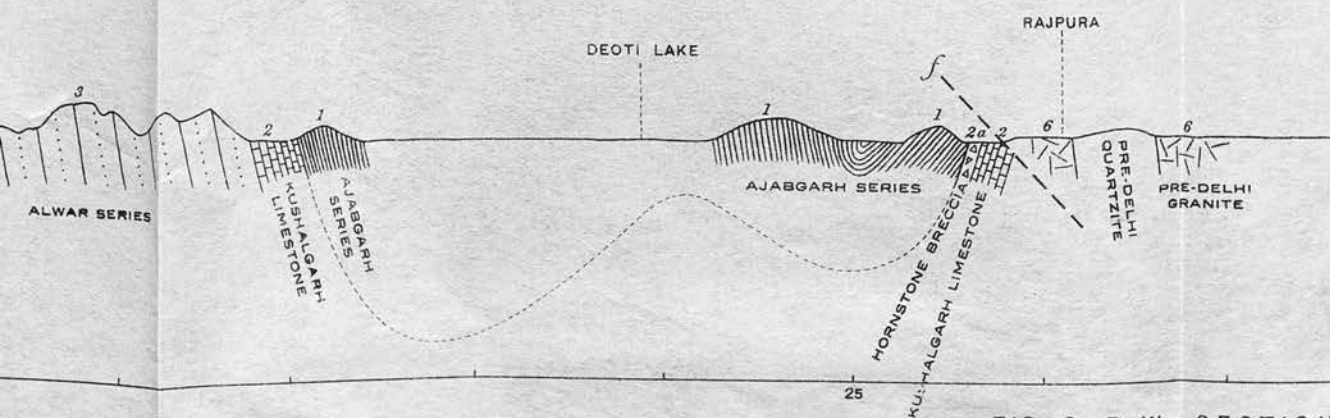
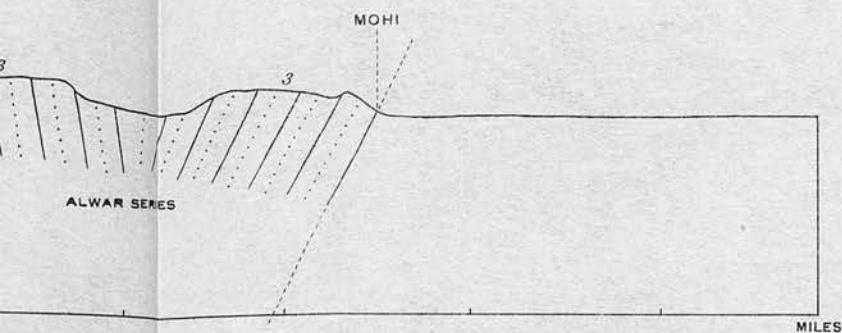
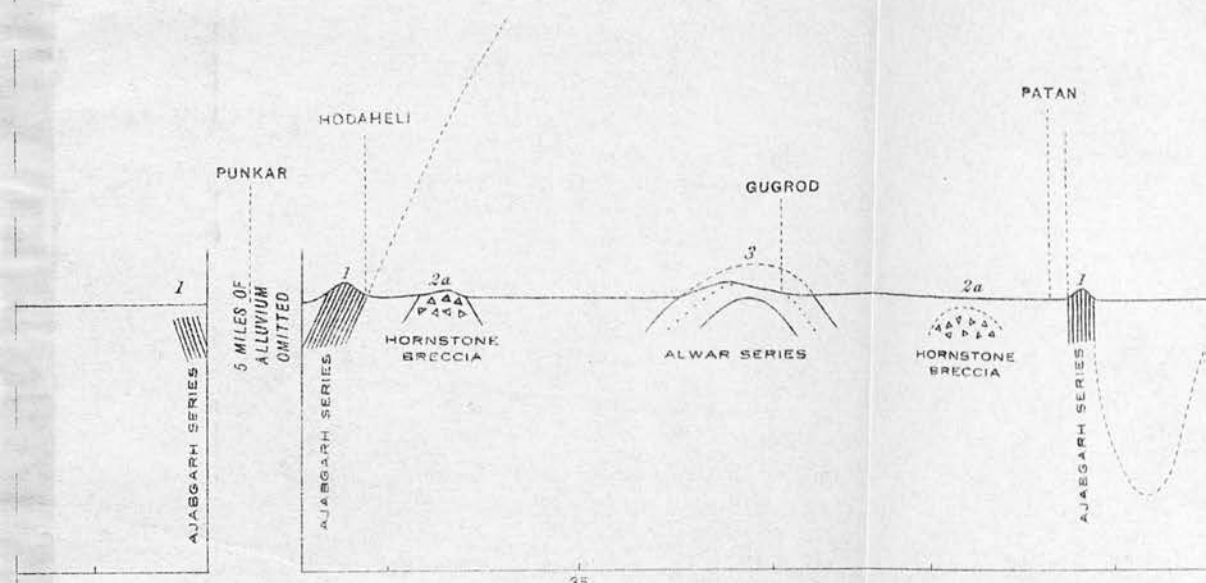
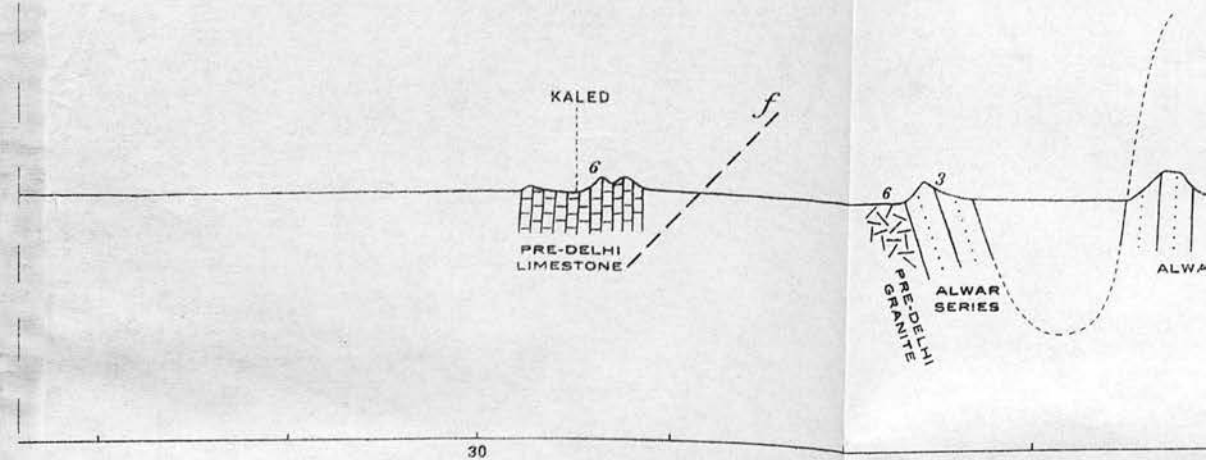


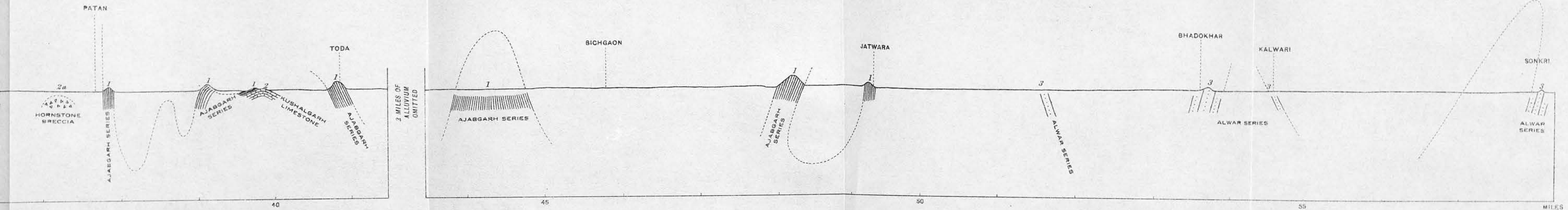
FIG. 3. E.-W. SECTION















FROM PUNKAR TO SONKRI (E. 12° S.) [Line H. H. of map.]



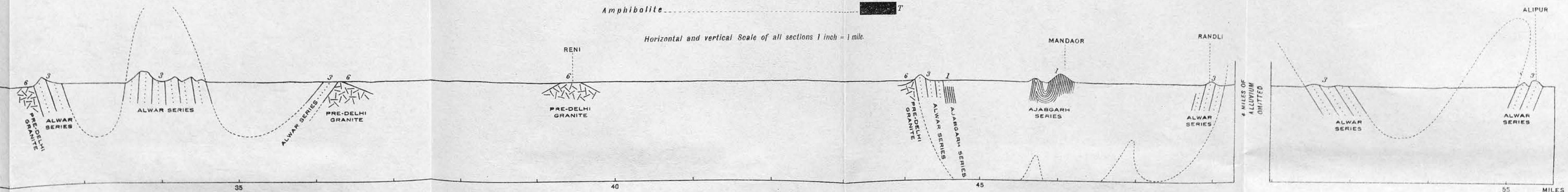
ALONG LAT. 27° 10'; FROM RAISAR TO ALIPUR. [Line K. K. of map.]

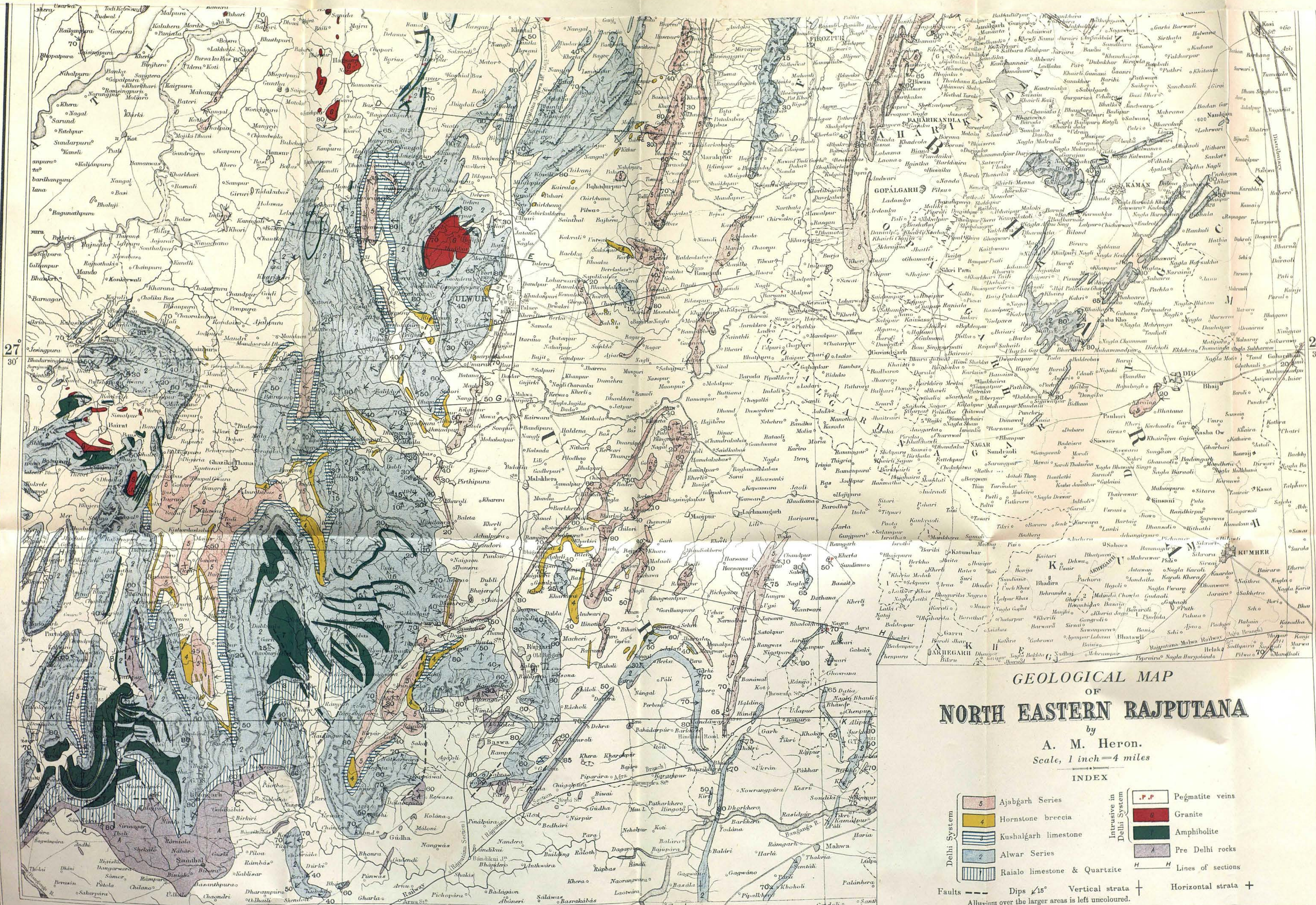


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| Amphibolite..... |  | T |

Horizontal and vertical Scale of all sections 1 inch = 1 mile.





GEOLOGICAL MAP
OF
NORTH EASTERN RAJPUTANA

by
A. M. Heron.
Scale, 1 inch = 4 miles

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| | Ajabgarh Series | | Granite |
| | Hornstone breccia | | Amphibolite |
| | Kushalgarh limestone | | Pre Delhi rocks |
| | Alwar Series | | Lines of sections |
| | Raialo limestone & Quartzite | | |
- Faults --- Dips $\angle 15^\circ$ Vertical strata + Horizontal strata +
Alluvium over the larger areas is left uncoloured.



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